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OPTIMUM SITE EXPOSURE CRITERIA FOR SO_2 MONITORING

by

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ABSTRACT

This report presents procedures and exposure criteria for selecting SO_2 monitoring sites. General monitoring program elements and data uses are first reviewed and summarized; from this summary a list of specific siting objectives is developed. Site selection procedures were then prepared for specific site types each of which was associated with either a grouping of siting objectives or with an individual objective.

Because of the variety of SO_2 siting objectives, the averaging times associated with the air quality standards, the physical environments in which sites could be located, and spatial scales of representativeness, an SO_2 monitoring "universe" was first constructed from which the final list of monitoring site types and associated site selection procedures was developed.

Detailed procedures are provided for selecting sites to measure regional mean concentrations, interregional SO_2 transport, representative concentrations for areas of various sizes, peak concentrations in urban areas, and emergency episode levels. Procedures for selecting sites to monitor impacts from isolated point sources in a variety of physical settings including valleys and coastal areas are also provided. A general guideline for locating sites in mountainous terrain is included. Recommendations for inlet height and orientation, and for minimizing undue influence from nearby sources are presented. The rationale behind the various procedures and other support documentation is given.

Sources of special information and data relevant to selecting specific sites and guidelines for determining locations of sites for satisfying specific objectives are provided in a series of appendices. A bibliography, conveniently arranged according to specific subject areas, is included.

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SUMMARY

Studies (e.g., Yamada, 1970; and Jutze and Tabor, 1953) show that little consistency exists among monitoring site locations, their surrounding physical environments, and the uses for which the data are intended. This report was prepared to provide a means for achieving such consistency, for SO_2 monitoring, by establishing a logical procedure by which various data uses can be related to optimum site locations and instrument inlet exposures. The physical characteristics of the area surrounding the site were also considered in developing the relationships.

To give a national perspective to SO_2 emission patterns and problems, in the northern areas the residential space-heating and power plant emission categories are the largest. In the south, emissions from transportation, power plants, and industrial processes dominate; while in the west the industrial process emission category is the largest. Over the entire nation, SO_2 problems can range in complexity from single source impacts over flat terrain to impacts from multi-source urban-industrial complexes located in complex terrain settings.

There are twelve major uses for which SO_2 data are required.

1) Judging attainment of SO_2 NAAQS.

2) Evaluating progress in achieving/maintaining the NAAQS or state/local standards.

3) Developing or revising state implementation plans (SIPs) to attain/maintain NAAQS; evaluating control strategies.

4) Reviewing new sources.

5) Establishing baseline air quality levels for preventing significant deterioration (PSD) and for air quality maintenance planning (AQMP).

6) Developing or revising national SO_2 control policies [e.g., new source performance standards (NSPS), tall stacks, supplementary control systems (SCS)].

7) Providing data for model development and validation.

8) Providing data to implement the provisions of the Energy Supply and Environmental Coordination Act (ESECA) of 1974.

9) Supporting enforcement actions.

10) Documenting episodes and initiating episode controls.

11) Documenting population exposure and health research.

12) Providing information to:
    a) public - air pollution indices; and
    b) city/regional planners, air quality policy/decision makers - for activities related to programs such as air quality maintenance planning (AQMP), prevention of significant deterioration (PSD) and the preparation of environmental impact statements.

The above uses of SO_2 data were determined from a literature survey. For the most part, they are broadly program oriented and constitute all of the monitoring requirements that are necessary to successfully implement those federal and state clean air policies that require the use of SO_2 ambient monitoring data.

The broad program orientation of the above uses made it very difficult to associate each with a specific monitoring site selection procedure. To obviate this problem, a list of specific monitor *siting objectives* was developed (also, mainly via literature survey) to provide a link between an intended use of the data and a specific site selection procedure. The siting objectives are couched in terms more reflective of the means by which the appropriate data will be obtained rather than in terms having a broad program connotation. The siting objectives and associated data uses are listed below.

- <u>Determination of peak concentrations in urban areas</u>
  - major data uses: 1, 2, and 3.
  - other data uses: 8, 9, and 12.

- <u>Determination of the impact of individual point sources in multi-source urban settings</u>
  - major data uses: 3, 4, 6, 8, and 9.
  - other data uses: 12.

- <u>Determination of the impact of isolated point sources</u>
  - major data uses: 3, 4, 6, 8, and 9.
  - other data uses: 5 and 12.

- <u>Assessment of Interregional SO_2 Transport</u>
  - major data uses: 2, 3, 5, and 12.

- <u>Determination of base concentrations in areas of projected growth</u>
  - major data uses: 5 and 12.

- <u>Initiation of Emergency Episode Abatement Actions</u>
  - major data uses: 10 and 12.

- <u>Determination of Population Exposure</u>
  - major data uses: 11 and 12.

- Assessment of Background Concentrations in Rural Areas
  - major data uses: 5 and 12.
  - other data uses: 2 and 3.

- Diffusion Model Calibration and Refinement*
  - major data use: 7.

Each of the above siting objectives can be associated with a spatial scale. For example, a regional mean concentration is meant to represent conditions over a large area while the peak concentration zone in an urban area may be represented by a spatial scale no more than about a city block or so, in size. The spatial scales of interest in SO_2 monitoring (and, perhaps, other pollutants as well) can be classified as follows:

- Microscale. Ambient air volumes with dimensions ranging from meters up to about 100 meters are associated with this scale.

- Middle Scale. This scale represents dimensions of the order from about 100 meters to 0.5 kilometers and characterizes areas up to several city blocks in size.

- Neighborhood Scale. Neighborhood-scale measurements would characterize conditions over areas with dimensions in the 0.5 to 4.0 kilometer range.

- Urban Scale. Urban-scale measurements would be made to represent conditions over areas with dimensions on the order of 4 to 50 kilometers.

- Regional Scale. Conditions over areas with dimensions of as much as hundreds of kilometers would be represented by regional-scale measurements. These measurements would be applicable mainly to large homogeneous areas, particularly those which are sparsely populated.

- National and Global Scales. These measurement scales represent concentrations characterizing the nation and the globe as a whole.

Urban scale conditions would, in general, require more than a single monitoring site to characterize them. For this reason, monitoring sites established for measuring concentrations representing volumes of this scale were not addressed in this report. National and global scale measurements are not of sufficient interest to state and local agencies to justify specific treatment. The remaining scales are relevant to SO_2 monitoring.

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* Since it is difficult to anticipate the monitoring requirements of diffusion model calibration and refinement projects, and impossible to generalize related siting guidelines, an attempt to do so was considered beyond the scope of the objectives of routine monitoring which this report addresses.

In SO_2 monitoring, a distinction must be made between the spatial scale desired to be represented by a single measurement and the scale actually represented by that measurement. The former is a function only of the intended use of the data and associated siting objective while the latter is a function mainly of the horizontal concentration gradient prevailing around the site. For long averaging times, urban concentrations generally decrease outward from maxima near the center with steep concentration gradients prevailing over the central portions of a city, while in the outer portions (adjacent suburbs and rural areas) the gradients would be moderate to flat. Therefore, over the central portion of the city, middle and neighborhood spatial scales would be those most likely to be represented by single measurements; similarly, single measurements would represent neighborhood scales in suburban areas and regional scales in rural areas.

SO_2 monitoring sites may be classified as either proximate or general level. Proximate sites are oriented toward measuring concentrations resulting from a specific source or group of sources; general level sites are associated with measurements of total concentrations where contributions from an individual source or a group of sources are either not required to be known or do not predominate. Generally, siting objectives (and associated monitoring sites) are either "pattern" oriented, such as sites established to measure urban peak concentrations, or they are associated with specified geographical areas such as areas of projected growth or locations of specific population groups.

SO_2 measurements should, depending on the specific siting objective and related data use, represent 3-hour, 24-hour and annual averaging times, which are those of the National Ambient Air Quality Standards for SO_2.

All of the above parameters regarding spatial scales, siting objectives, averaging times, etc. when combined with basic land use types and topographical settings, represent an SO_2 monitoring universe. From this universe, a set of five monitoring site types were established for which site selection procedures were developed.

I. General-Level, Regional-Scale Stations

a. General site location: located in areas of flat concentration gradients and low emission densities; usually homogeneously rural settings.

b. Siting objectives and related data uses:
- Assessment of background concentrations in rural areas
  - major data uses: 5 and 12.
  - other data uses: 2 and 3.
- Assessment of interregional SO_2 transport
  - major data uses: 2, 3, 5, and 12.

II. General-Level, Neighborhood-Scale Stations

a. General site location: located in areas of moderate SO_2 background concentration gradients, generally in areas adjacent to the central business districts (CBDs) of cities and suburbs.

CONTINUED

b. Siting objectives and related data uses:
- Determination of population exposure
  - major data uses: 11 and 12.
- Determination of base concentrations in areas of projected growth
  - major data uses: 5 and 12.
- Initiation of emergency episode abatement actions
  - major data uses: 10 and 12.

III. General-Level, Middle-Scale Stations

a. General site location: located mainly within CBDs of cities or industrial districts where SO_2 concentrations are the highest and concentration gradients are steepest.

b. Siting objectives and related data uses:
- Determination of peak concentrations in urban areas
  - major data uses: 1, 2, and 3.
  - other data uses: 8, 9, 10, and 12.

IV. Proximate, Middle-Scale Stations

a. General site location: located in the area of the highest ground-level concentration associated with an individual major SO_2 source or group of SO_2 sources. Sources may be located in either urban, suburban, or rural areas.

b. Siting objectives and related data uses:
- Determination of the impact of individual point sources in multi-source urban settings
  - major data uses: 3, 4, 6, 8, and 9.
  - other data uses: 12.
- Determination of the impact of isolated point sources
  - major data uses: 3, 4, 6, 8, and 9.
  - other data uses: 5 and 12.

V. Proximate, Microscale (mobile sampling) Measurements

General Comments. Microscale measurements are obtained via mobile sampling in regions of complex terrain and in urban areas. They are used mainly to define certain features of the SO_2 pattern such as peak concentrations associated with major point sources, particularly under atmospheric stagnation conditions, and impacts due to plume downwash. These measurements may be used in support of the siting objectives and related data uses associated mainly with Site Type IV above.

Each of these site types (except V, which is associated with mobile sampling) is associated with a basic procedural siting approach with variations from the basic approach being functions of the individual siting objective, averaging time and physical setting. The siting approaches are basically step-by-step procedures through which a siting area is first selected, then site choices are gradually reduced until the best choice site is selected.

Diffusion modeling results and graphical solutions to the Gaussian diffusion equation provide the basic initial guidance for locating the monitor siting area for nearly all objectives. An elimination process then follows, which is essentially a procedure for choosing a site location such that undue influences from nearby sources are eliminated or minimized. In this regard, several "interference distances" (ID) or minimum separation distances were calculated via Guassian diffusion equations. These IDs were determined such that the maximum concentration resulting at the monitoring site from a single source would be less than 2.6 $\mu g/m^3$ (which is the natural SO_2 background level) for sites located in rural areas, or less than 10 $\mu g/m^3$ (level or cleanest rural air) for sites located in urban or suburban areas. Different sets of IDs were calculated for urban, rural, and suburban diffusion conditions. Also, half-life values for SO_2 of one hour and three hours were used for urban and rural areas, respectively. The IDs are summarized in the tables below.

Source Types and Related Interference Distances*
For Regional-Scale Monitoring Stations.

Source Type	Interference Distance
Large point source (e.g., a 400 MW power plant).	30 km
Industrial Source (500 tons SO_2 per year).	10 km
Towns (various size population)	
50,000	22 km
25,000	15 km
12,500	10 km
6,000	7 km
Individual home	0.6 km

* Based on an undue influence concentration of 2.6 $\mu g/m^3$

Interference Distances for Three Development Intensities.

	Interference Distances[a]	
	Minor Sources (MSID)[b]	Point Sources (PSID)[c]
Urban	200 m	1,000 m
Suburban	100 m	2,200 m
Rural[d]	60 m	3,200 m

a Based on undue influence concentration of 10.0 $\mu g/m^3$.
b Minor sources include individual office building in the urban area (10^5 gal/yr #2 oil), small building in the suburban areas (10^4 gal/yr) and an individual home in the rural area (10^3 gal/yr).
c Point sources include any source that uses 10^6 gal. of fuel oil per year or more (see text).
d Rural settings adjacent to cities where steeper concentration gradients preclude regional scale stations.

It was inferred from the literature survey that the generally turbulent and well-mixed urban atmosphere produces SO_2 concentrations that are essentially uniform with height up to about mean building height; therefore, the exact vertical placement of the instrument inlet below this height was not important for averaging times of several hours or more. For guidance purposes, we chose a height of 0.8 of the mean building height in the urban area below which a site could be established (or instrument inlet placed).

The most important elements of the siting methodologies for establishing monitoring stations associated with each of the four major monitoring site types are tersely summarized below. Also included are some of the desirable physical characteristics of the site. These methodologies are described in much more detail in the body of this report (Section 4.0).

I. General-Level, Regional-Scale Stations

a. Siting Objectives: To measure regional mean concentrations and concentrations resulting from interregional transport processes.

b. Spatial Scale of Representativeness: Regional (up to 100s of km).

c. General Site Locating Methodology:
- Regional mean concentration measurements - site should be no closer than 30 km from nearest city in the direction that is least frequently downwind.
- Interstate-urban transport stations - locate site near state line on out-of-state urban area side.
- Interstate-general transport stations - locate site near windward state line.
- Intercity transport stations - locate site upwind of city in most frequent winter wind direction (to measure SO_2 entering city.

Topography should be uniform. Sites no closer than 30 km to a power plant, 22 km to a 50,000 population town, and 0.6 km to an individual home (see Section 4.2.1.1 for details).

d. Inlet Exposure Criteria: Avoid low-lying areas; choose open or sparsely forested areas; since SO_2 (away from point source) is well-mixed in vertical, inlet height of 3-10 m above ground is reasonable.

II. General-Level, Neighborhood Stations

a. Siting Objectives: To monitor emergency episodes, to measure exposures of specific populations to SO_2, and to measure base concentrations in areas of projected growth.

b. Spatial Scale of Representativeness: Neighborhood (0.5-4.0 km).

c. General Site Locating Methodology:
- Emergency episode stations - locate site near center of emission maxima of city. (Since models are unreliable in near zero wind, some verification via mobile sampling may be required.
- Population exposure stations - general location from pop. maps.
- Projected growth stations - general location from land use maps.

CONTINUED

Concentration gradient (from modeling) determines number of stations required and whether middle-scale siting procedures are to be used (see text, Section 4.3.2). Sites should be no closer than interference distance (ID) to specific sources in upwind direction (see Table 4-4).

d. Inlet Expsosure Criteria:
- Emergency episode stations - locate instrument inlet no higher than about 80% of the mean building height in local area, away from dusty areas (as a general rule) and between 1-2 m above the roof (see Table 4-3 for additional criteria).
- Population exposure/projected growth sites - additional criteria include locating inlet on windward side of building, 1-2 m out from building for non-rooftop locations.
- All sites - no significant SO_2 emission points on roof (see Table 4-5). In suburban areas, choose building of low height, preferably one story.

III. General-Level, Middle-Scale Stations

a. Siting Objectives:
- Major objective - to measure peak concentrations in urban areas.
- Secondary objective - to measure exposure of specific populations to SO_2 and determining base concentration in projected growth areas where steep concentration gradients prevail.

b. Spatial Scale of Representativeness: Middle (100-500 m).

c. General Site Locating Methodology: Diffusion model results including annual and 3-hour/24-hour near "worst case" patterns provide most of the basic guidance for locating the urban peak stations. Diffusion meteorologists should be consulted regarding exact form of model, inputs and assumptions; 100-m distance near maximum resolving power of most models. Mobile sampling recommended to confirm locations of where the 3-hour/24-hour peaks occur and effects from downwash (see Section 4.4 for more details of methodology). Methodology for population/growth stations is similar to that for neighborhood stations except that IDs appropriate to middle scales are used (see main text).

d. Inlet Exposure Criteria: Exposure criteria are the same as those for the non-episode neighborhood scale stations (see Table 4-5); inlet height, 80% of mean building height in local area; no significant SO_2 emission points on roof. Locate inlet on winter windward side of roof. If trailer site, avoid parking lots in general and lots around which there are buildings using large amounts of fuel oil(to prevent undue influences due to plume downwash effects).

IV. Proximate, Middle-Scale Stations

a. Siting Objectives: To measure impacts from major point sources located in multi-source urban settings and impacts from isolated point sources.

b. Spatial Scale of Representativeness: Middle (100-500 m).

CONTINUED

c. General Site Locating Methodology: Diffusion model results including annual and 3-hour/24-hour near "worst case" patterns provide most of the basic guidance for locating urban stations (see Section 4.5). For isolated point source sites, use graphical solutions to diffusion equations (see Section 4.6). Special procedures are utilized for locating sites in valleys and in near coastline settings (see Sections 4.6.2, 4.6.3). In extremely rough terrain, only general guidance is given; major points to consider include the following -

- In regions subject to at least occasional periods of low mixing depths, locate monitors in basins that have inlets for SO_2 source plumes.
- Site monitors at ridgetop locations in the general downwind directions from the source, or perhaps at ridgetop locations surrounding the source, particularly those nearest the source at near effective plume height elevations.
- Site monitors in passes that may receive the plume advected either by drainage or channeled winds.
- A complete survey of the entire area influenced by the SO_2 source would almost certainly be required in all situations. Visual observations, aerial photography, mobile sampling, remote sensing, etc. would probably be the most important means for conducting such surveys.

d. Inlet Exposure Criteria: For urban stations, the inlet exposure criteria are shown in Table 4-5. Criteria for isolated point source monitoring sites are similar to those of regional stations; exceptions are -

- The height of the inlet should be no higher than about 3-5m above ground in all cases.
- No major fossil fuel-burning sources between source and site.
- No need to avoid wake effects of small buildings or clumps of trees.

In irregular/rough terrain, choose well exposed areas. Establish monitoring site off to one side of very large obstacles.

A set of appendices are included to provide guidance for selecting background information and data appropriate to the siting objective. Information on meteorology, land use, topography, demography, diffusion models, "worst case" meteorology and associated pollutant patterns, and mobile sampling is included. Such information is used as an aid to identifying the general siting area then in selecting the final site location within the area.

The rationale underlying the site selection procedures are embodied in three basic elements:

1) Determining the general location of the monitoring site, mainly via diffusion modeling.

2) Refining the location to minimize undue influences from nearby sources, including meteorological effects.

3) Placing the instrument inlet in such a location to avoid local contamination.

Multi-source Gaussian models and graphical solutions to the Gaussian diffusion equation provide the basic means of ascertaining the general location of the monitoring site, except in areas of extremely rough terrain. In areas characterized by terrain of moderate roughness, and in valleys, modification of the meteorological input to the model may be necessary. A diffusion meteorologist should be consulted in such situations to help determine the nature of such modifications and also in performing the modifications. Regarding the monitoring of the 3-hour/24-hour short-term peak concentrations in urban areas, the simulations of the 3-hour and 24-hour near-worst case patterns are recommended to estimate appropriate site locations. Again a diffusion meteorologist is recommended to be consulted to aid in determining such patterns, as well as in judging the potential for any plume downwash effects. Some guidance regarding the former is provided in Appendix B. Emergency episode stations should be located in the very heart of the maximum SO_2 emission density zone of an urban area; during air stagnations wind speeds are low and directions are variable so the maximum concentration should occur where the emission density is a maximum. Most of the impact at ground level will be from low-level SO_2 sources. Appropriate site locations can best be found by using gridded emission inventory data with most of the weight being given to the area source fraction of the inventory. The heat island mechanism may produce maximum concentrations near the wind inflow convergence point which also may be located near the center of maximum SO_2 (and heat) emission zone of the city. This justifies considering the emergency episode station as an alternative site for measuring the 3-hour peak concentration.

The natural SO_2 background level as reported by Robinson and Robbins (1970), 2.6 $\mu g/m^3$, was deemed to be the undue influence level for determining IDs in rural areas. The IDs were calculated via solutions to the Gaussian diffusion equation using that concentration and the assumptions and meteorological conditions as shown in the following table.

Configurations and Emissions for Typical Source Types Assumed in Determining Interference Distances for Regional-Scale Stations

Source Type	Characteristic Emission Period	Fuel Rate S Content (%)	Source Configuration	Emission Rate (g/sec)	Meteorology		
					Wind Speed	Stability Class	Effective Ht. (m)
Power Plant (400 MW)	365 days/yr	280 × 10^6 gal #6 oil @ 1% S	Point, uniform wind over 22.5° sector	575	5 m/sec	D	300
Industrial Space Heat (500 T SO_2/yr)	Winter Quarter (DEC, JAN, FEB)	14 × 10^6 gal #6 oil @0.5% S	Point	58	5 m/sec	D	200
Small Town (25,000 pop., 6000 homes)	Winter Quarter (DEC, JAN, FEB)	10^3 gal/home #2 oil @ 0.2% S	Area Source 4 mi^2	10	1 m/sec	D	0
Individual Home	Winter Quarter (DEC, JAN, FEB)	10^3 gal #2 oil @ 0.2% S	Point	.0016	1 m/sec	F	0

With respect to the physical characteristics of the area in the immediate vicinity of the site, their effect on critical meteorological variables and how these relate to the final site location and the placement of the instrument inlet, the literature survey yielded much information from which the following conclusions could be inferred.

- Mixing produced by mechanical turbulence and wake effects of larger obstacles over moderately rough, natural terrain averages the pollutant over space which lessens the concern of exact site location and inlet placement in rural areas.

- Micro-scale urban features substantially increase mixing and promote uniformity of pollutant levels from mid- and far-distant sources. This mixing between source and monitoring site reduces the monitoring site selection problem to the consideration of only near sources (less than the interference distance). The bulk of the plume material was assumed to be held within a 10° sector downwind of the source and a 20° sector downwind of the sources nearest to the prospective monitoring site.

- A plume entering a building wake cavity will be rapidly mixed throughout the cavity. The resulting volume source configuration can be approximated by considering the source as having been released from a virtual point source upwind of the building.

- The uniform mixing principle is not absolute and cavity flows often build, get swept away, and reform, leading to large "puff" type releases.

- Except for near the windward edge of a city, a vertically uniform SO_2 distribution up to at least the mean building height over the area of interest in the city can be assumed. The choosing of 0.8 $\bar{H}$ (or lower) for inlet location above the ground is somewhat arbitrary, but was meant to insure that the instrument (or inlet) would be placed at a point in the vertical where the measured levels would approximate those existing near the breathing zone 5-6 feet above the ground.

- If pollutant release is known to be well within a cavity (e.g., emissions from a vehicle in a deep street canyon) averaging will not be complete and concentration fluctuations and gradients are apt to be found within the flow. Minimum velocities and maximum concentrations should be found near the ground on the leeward side of the obstacle. This is the justification for avoiding trailer locations just downwind of buildings with large stacks. This situation is generally precluded, however, if the interference distance criteria are satisfied.

- Pollutants from sources located downwind of a building may be emitted into the wake cavity behind the building. The reverse flow of the wake may advect pollutants up to the roof of the building to at least one-half of the width of the building from the downwind edge.

This observation is the rationale for recommending that inlet placement locations be on the windward side of the building. It also justifies the recommendation of not having SO_2 sources on the roof of the building chosen for the monitoring site or inlet location.

In summary, the guidelines presented here provide a basis for selecting monitoring sites to satisfy specific siting objectives to ensure the compatibility of the data obtained with the ultimate use of the data. Also, the guidelines require specific procedures to be followed; these procedures involve diffusion model analyses, consideration of the effects of natural and urban topography on plume-carrying winds, and nearby source effects. All of these elements will provide a physical basis for interpreting monitoring data. This will ensure the site selector and data user that the data reasonably represent actual conditions over the appropriate spatial scales. This ensurance is critical since decisions regarding control plans and strategies, which may have severe economic impacts, are usually based on the interpretation of such data.

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1.0 INTRODUCTION

1.1 GENERAL

Sulfur dioxide (SO_2) is a natural constituent of the air. Globally, about one-half of all SO_2 in the atmosphere comes from natural sources (Robinson and Robbins, 1968). These natural sources are, however, quite diffuse and lead to background concentrations estimated to be a small fraction of a part per billion (parts of air). In contrast, the emissions from anthropogenic processes are relatively quite intense. As SO_2 is dispersed in the atmosphere, its concentration is reduced from noxious levels near the sources to levels comparable to that of SO_2 from natural sources. The general nature of SO_2 (or any pollutant) monitoring, then, is to measure the time and space variability of concentrations from the region of the source, or sources, to where the pollutant has become sufficiently dilute. Such measurements are required to satisfy monitoring program goals or data uses such as determining population exposures and ascertaining compliance with air quality standards.

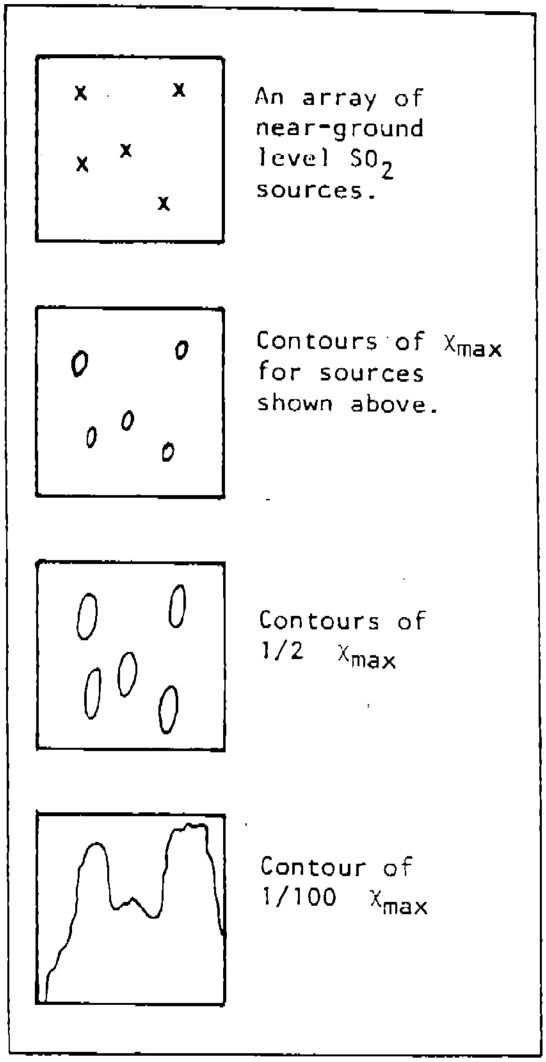

FIGURE 1-1. Concentration contours from an array of sources with steady conditions.

Since the dominant anthropogenic sources of SO_2 emissions are from stationary combustion devices, the most striking characteristic of typical SO_2 concentration patterns if that the concentration peaks reproduce the source patterns (see Figure 1-1). Monitoring for the concentration maxima averaged over any time scale may be accomplished with great accuracy by putting an instrument in every chimney. Obviously, it is of more interest to determine time and space patterns of SO_2 concentration away, but not too far away, from one or more sources. Concentrations very far away from all sources must be low; i.e., they approach the global average, and their patterns would contain features associated with only the longest time scales or the broadest space scales.

In the region between "too near" and "too far" from a source, a significant concentration may be expected over only perhaps 5 percent of the area at any one time (see Figure 1-2), because the wind comes from only one direction at a time. This is an order of magnitude rule-of-thumb, no matter what the minimum concentration of interest is. Any given monitor permanently placed in hopes of defining such a region would have one chance in twenty of detecting any SO_2 above the limit, even if all wind directions were equally likely. Also, the varying inner and outer limits of the region, due to the varying dispersive power of the wind would reduce the chances further. In situations where a given wind direction is significantly more likely than others, the chances are significantly increased, but still not as large as one would like. Therefore, instrument siting to monitor a single source even in an ideal environment free of micro- or meso-scale local effects such as topography, cavity wakes, or localized thermal effects is not a straightforward procedure.

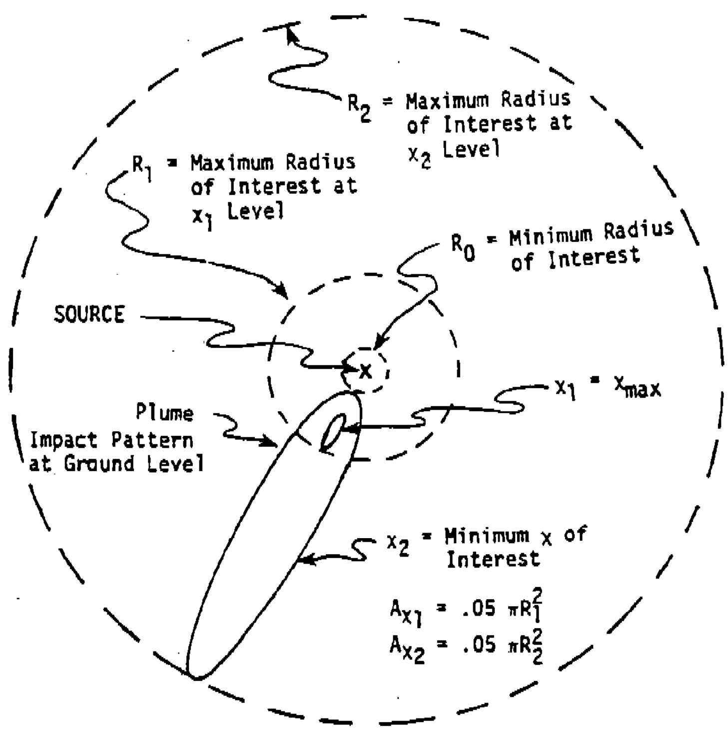

FIGURE 1-2. Instantaneous and potential regions of significant pollution concentration from a single source.

If many sources are near enough to each other so that their "circles of concern" (see Figure 1-2) overlap, then sources relatively far from a potential monitoring site will contribute a relatively steady "background" concentration upon which the relatively narrow plumes from nearer sources will be superimposed more randomly as they undulate past the site (see Figure 1-3). For a widespread and reasonably dense array of homogeneous sources, as, for example, in a large urban residential area, long-term mean concentrations can be determined quite accurately at any site. If the source array contains one or a few sources that are much larger than the rest which are relatively homogeneous, the problem of finding the background levels is as straightforward as for the homogeneous sources alone, but the problem of locating the peaks is as difficult as for the single source.

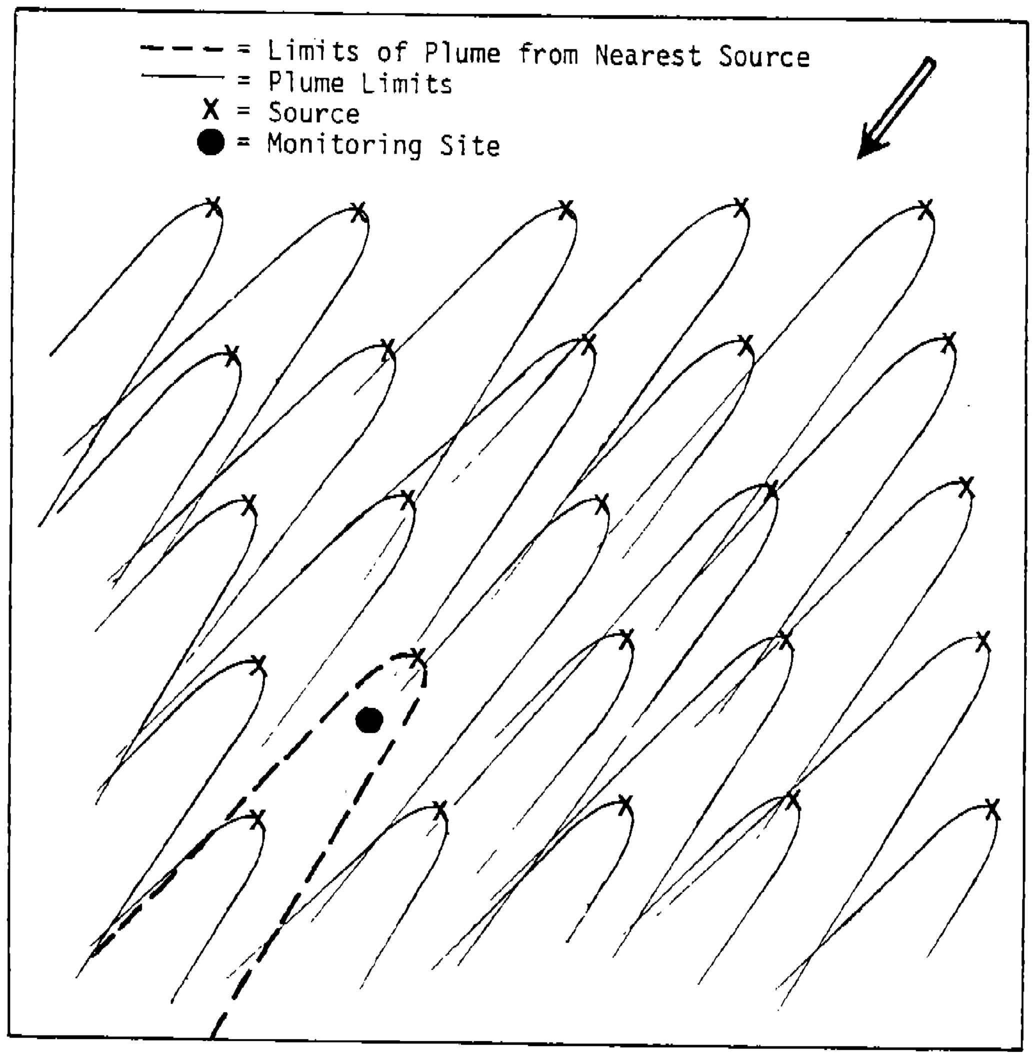

FIGURE 1-3. Superimposed plumes from multiple sources.

1.2 GEOGRAPHICAL AND SOURCE CHARACTERISTICS OF SO_2 EMISSIONS

The relative importance of the various SO_2 source categories varies geographically as shown in Table 1-1. In the colder areas of the north, exemplified by the Boston Air Quality Control Region (AQCR), commercial and residential heating is the largest category with 48.6 percent of the total for that AQCR. Farther south, the transportation, power generation, and industrial process emission categories are dominant, as indicated by the Atlanta AQCR summary. In the western states, the industrial process category is the largest with 40.1 percent and 37.6 percent of the total SO_2 emitted in the Denver and Los Angeles AQCRs, respectively. Transportation sources are also very significant in the west. In the Dallas/Fort Worth AQCR, SO_2 emissions from power generation are very small (3 percent of the total) because of the use of relatively sulfur-free natural gas. The largest category here is transportation (43.2 percent), followed by industrial processes (23.7 percent). In Arizona and Texas (as a whole) more than 80 percent of the SO_2 is emitted from smelters and refineries (Cavender, et al., 1973).

TABLE 1-1*

Sulfur Oxide Emission Inventories for the United States
and for Selected Air Quality Control Regions,
(NEDS Data for 1972)

Geographical Area	United States	Boston AQCR	Atlanta AQCR	St.Louis AQCR	Dallas, Ft.Worth AQCR	Denver AQCR	Los Angeles AQCR
	SO_2 Emissions in 10^3 Tons/Year						
Total Sulfur Oxide Emissions	32,000	332	94.7	1,234	17.3	33.5	238
Source Cagetory	Percentage of Sulfur Oxide Emissions by Source Category						
Stationary Source Fuel Combustion							
Electric Power Plants	54.3	41.6	70.8	76.2	3.0	34.2	16.8
Industrial	15.3	8.2	5.6	6.0	5.0	10.4	14.6
Commercial and Residential	7.1	48.6	5.7	1.9	19.8	5.3	18.8
Industrial Processes	21.1	0.5	12.3	15.3	23.7	40.7	37.6
Other Stationary Sources	0.2	0.1	0.5	0.1	5.3	0.2	1.6
Transportation Sources	2.0	1.0	5.1	0.5	43.2	9.2	10.6

* Taken from NAS (1975).

About two-thirds of SO_2 emissions occur in urban areas, with very large fractions contributed by industrial, commercial, and residential heating. These sources are also emitted near the ground which increases their ground-level impact. In rural areas, much of the SO_2 is emitted by a relatively small number of large sources such as smelters. Also, about one-half of the nation's power plants are located in rural areas. Although power plants comprise the largest emission category, their SO_2 is emitted from tall stacks which reduce ground-level impacts.

It will be seen later (in Section 4.0) that the physical configuration of the SO_2 source (i.e., point versus area source), whose SO_2 air quality impact is to be monitored, is important in regard to specific siting procedures. Point sources include large individual sources such as power plants and certain industrial processes. Commercial/residential heating and transportation categories are considered collectively as "area" sources.

1.3 SITE LOCATION STANDARDS

Most of the literature reporting air quality data and data summaries (e.g., EPA, 1973) emphasizes that interpretation of the data must be tempered by an understanding of the limitations imposed by inadequacies of surveillance methodologies. These inadequacies include inconsistencies between the specific objectives for which a monitoring station is established and the intended use of the resulting data and sampling maldistributions in both a geographical and temporal sense; these have been brought about by non-uniform siting procedures and/or a lack of an understanding of the atmospheric processes that affect the temporal and spatial distributions of pollutants. To illustrate these points, EPA (1973a) shows maximum 24-hour SO_2 concentration measurements within individual cities varying typically by a factor of from 5 to 10, and in extreme cases by 100 or more. Ott (1975) has shown similar variations in carbon monoxide measurements in United States cities. Clearly, data from most of these sites are not representative of the cities as a whole, but merely reflect what is occurring in the immediate vicinity of the sites.

Yamada (1970) showed that little consistency existed among sampling site locations and instrument inlet exposures. His study was based on a national survey of monitoring site characteristics. Further, the early Continuous Air Monitoring Program (CAMP) stations had inlet locations from 10 to 15 feet above the ground (Jutze & Tabor, 1963) while most state network station inlets were located on building roofs. A similar situation presently exists, although the development and deployment of instrumented trailers, of generally uniform dimensions, has reduced the problem somewhat.

From the above discussion, it is clear that a need exists for objective, uniform procedures for locating and categorizing SO_2 monitoring stations consistent with the intended use of the resulting data.

1.4 THE ORGANIZATION OF THIS REPORT

In Section 2.0, the major uses of SO_2 monitoring data is reviewed and a list of siting objectives, each consistent with a specific data use or group of uses is developed. It will be seen that the siting objective (along with the spatial scale of representativeness) is the major controlling factor in determining the desired physical characteristics of a site and its surroundings.

Section 3.0 discusses two basic monitoring network concepts, the spatial scales of representativeness relevant to SO_2 monitoring, and an SO_2 monitoring universe. A full review of these topics provides a basis to proceed with the development of the siting procedures which are discussed in Section 4.0.

Section 4.0 is the working part of the report and provides detailed step-by-step procedures for locating monitoring sites and the exposure of instrument inlets to satisfy the requirements for the various siting objectives. The discussion proceeds from the largest spatial scale to the smallest considered.

In Section 5.0, the rationale behind the site location procedures and other support documentation are presented. Topics include some of the relevant meteorological aspects of air pollution, topographical effects, urban modifications, washout/rainout, and chemical/physical interactions.

In determining monitoring site locations, the site selector will be required to use information and/or techniques with which he may be unfamiliar. To obviate this problem, a set of appendices has been included which describe the various kinds of data and techniques required as well as the sources from which these may be obtained. Topics addressed include a general approach for determining worst case meteorological conditions, the sources of meteorological and land use data, a list of available air quality models which may be useful in selecting a site, and some concepts of mobile sampling.

A bibliography (see Appendix F) is included showing a sample of the body of information available on all relevant topics covered in this report.

2.0 SO_2 DATA USES AND RELATED SPECIFIC MONITOR SITING OBJECTIVES

In this section, general SO_2 monitoring program elements and uses of SO_2 data are first reviewed; then, based on the review, a list of specific monitor siting objectives is developed. The main thrust of this section is to give some perspective to the various data uses and to relate them to the specific siting objectives. This latter point is important since it was from the siting objectives that a relatively small group of monitoring site types was developed for which site selection procedures and instrument inlet exposure criteria were prepared (Section 4.0).

2.1 GENERAL

Selecting and/or redistributing SO_2 monitoring sites on a priority basis is becoming critical in view of issues that have arisen since the promulgation of the Clean Air Act Amendments of 1970.* For example, air quality maintenance planning (AQMP) (Federal Register, 1973a), prevention of significant deterioration (PSD) (Federal Register, 1974), transportation control plans (Federal Register, 1973b), supplemental control systems (SCS) or intermittent control strategies (Federal Register, 1973c), and the Energy Supply and Environmental Coordination Act (ESECA) of 1974 have resulted in, either directly or by implication, requirements for expanded and/or reconfigured air monitoring networks. In addition, complexities and problems associated with photochemical pollutants (e.g., Stasiuk and Coffey, 1975; and Spicer, et al., 1976) which were unforeseen at the time of the passage of the "Amendments" will require an expansion of photochemical and photochemical precursor pollution monitoring. The total impact of these issues will require a reallocation of resources for ambient air monitoring. It will, therefore, be essential for the site selector to optimize ambient SO_2 monitoring systems in response to these new monitoring requirements.

Foremost in the discussion of SO_2 monitoring are the National Ambient Air Quality Standards (NAAQS) which must be attained and maintained in each AQCR across the country. These standards are summarized in Table 2-1. The primary standards were set to protect human health and the secondary standard was set

* The "Act" resulted in the requirement for the states to prepare, adopt, and implement air pollution control plans or "state implementation plans" (SIPs) to attain and maintain air quality standards (Federal Register, 14 August, 1971). These plans included provisions for the design, establishment, and operation of air monitoring networks.

to protect the public welfare. The primary standards were to be attained in each AQCR by June of 1975 and the secondary standards attained within a reasonable time thereafter.

TABLE 2-1

NAAQS for SO_2

	Primary Standards	Secondary Standard
Annual Average	80 $\mu g/m^3$	---
24-hour Maximum	365 $\mu g/m^3$	---
3-hour Maximum	---	1300 $\mu g/m^3$

2.2 USES OF SO_2 MONITORING DATA

The list of SO_2 data uses presented below was compiled from a literature survey (see Appendix F). The order in which the uses are listed does not necessarily reflect the priority or relative importance of the uses; obviously, the priority of a given use in a given area would depend on the nature of the SO_2 problems that characterize that area. However, most of the uses that are listed are common to most areas of the country and are generally required to successfully implement those federal and state clean air policies that require the use of ambient SO_2 data.

1) Judging attainment of SO_2 NAAQS.

2) Evaluating progress in achieving/maintaining the NAAQS or state/local standards.

3) Developing or revising state implementation plans (SIPs) to attain/maintain NAAQS; evaluating control strategies.

4) Reviewing new sources.

5) Establishing baseline air quality levels for preventing significant deterioration and air quality maintenance planning.

6) Developing or revising national SO_2 control policies [e.g., new source performance standards (NSPS), tall stacks, supplementary control systems (SCS)].

7) Providing data for model development and validation.

8) Providing data to implement the provisions of the Energy Supply and Environmental Coordination Act (ESECA) of 1974.

9) Supporting enforcement actions.

10) Documenting episodes and initiating episode controls.

11) Documenting population exposure and health research.

12) Providing information to
   a) public - air pollution indices; and
   b) city/regional planners, air quality policy/decision makers - for activities related to programs such as air quality maintenance planning (AQMP), prevention of significant deterioration (PSD), and the preparation of environmental impact statements.

2.3 MONITOR SITING OBJECTIVES

The above data uses are expressed in rather broad terms and are generally program oriented. For this reason, it was difficult to associate a particular data use with a specific site selection procedure. To obviate the problem, a list of siting objectives was developed to provide a link between data uses and specific site selection procedures. The various siting objectives were developed such that each could be related to a specific type of monitoring site that would yield data of a level of quality and spatial and temporal representativeness appropriate for its intended use. Some of the siting objectives are couched in terms more reflective of the means by which the appropriate data will be obtained rather than in terms having a broad program connotation. Other siting objectives are worded closely to their related data uses, since in these cases the intended use is rather specific (e.g., episode monitoring). The monitor siting objectives and their related data uses are listed and discussed in the following sections.

2.3.1 Siting Objective 1 - Determination of Peak Concentration in Urban Areas

State and EPA policies and regulations require that SO_2 levels be brought within the primary NAAQS by June of 1975 and the secondary NAAQS within a reasonable time after that date, and that both are maintained thereafter. Maximum annual, 24- and 3-hour concentrations of SO_2 are usually found in urban centers where the use of sulfur-containing fossil fuel for space heating results in extremely high SO_2 emission densities. Subsequently, people living and working in these areas may be subject to both chronic and acute effects brought about by exposure to these high concentrations. The problem is exacerbated by SO_2 emissions from power plants which are often located in the larger urban centers.

SIP control strategies for SO_2 abatement are usually keyed on achieving the NAAQS at these points of maximum concentration (therefore, inherently related to the maximum economic impact of the strategy). Monitoring sites should be located at or near these points of maximum concentrations as revealed by modeling, to provide a continuing assessment of the situation. The most relevant uses for which such data are required are as follows:

- Judging attainments of SO_2 NAAQS (use 1)*.

- Evaluating progress in achieving/maintaining the NAAQS or state/local standards (use 2).

- Developing or revising state implementation plans (SIPs) to attain/maintain NAAQS; evaluating control strategies (use 3).

Such data will also be relevant to the implementation of the ESECA of 1974 (use 8) in those cities where there are power plants subject to the provisions of the ESECA.** Other uses include the supporting of enforcement actions (use 9) and in providing information to the public, city/regional planners, and air quality decision makers (use 12).

2.3.2 Siting Objective 2 - Determination of the Impact of Individual Point Sources in Multi-Source Urban Settings

This siting objective is similar to Objective 1 except that the monitor is placed at or near the maximum ground-level impact point caused by an individual point source located in an urban area. Because of background "noise" produced by other urban sources, monitor placement and data interpretation must also be done in conjunction with diffusion modeling.

This siting objective is related particularly to the ESECA of 1974 (use 8) which was enacted in response to projected shortages of fuel oil and/or diminished confidence of availability of supplies of such fuels. Under the Act's provisions, sources--mainly power-generating stations--may be required to convert to coal-burning. The conditions of the conversion will depend on the status of the AQCR with respect to the NAAQS. If the NAAQS are not being attained, a regional limitation (on SO_2 emissions) applies and all provisions of the SIP must be met before the conversion. If the NAAQS are being attained, then a primary standard condition applies which results in a variance from SIP emission limits and still results in attainment of the NAAQS. This siting objective particularly addresses the situation for such subject sources located in urban areas.

Another situation applicable to this siting objective is that of a single source located in an urban area that contributes overwhelmingly to SO_2 pollution in that urban area. In such a situation, it would be very desirable to monitor the maximum ground-level contribution from that source since the attainment and maintenance of the NAAQS in the area would be highly dependent on the effectiveness of control measures applied to that source. In this connection, data from monitoring stations so located could be used for:

- Developing or revising SIPs to attain/maintain NAAQS; evaluating control strategies (use 3).

---

* Uses are listed from 1 to 12 in Section 2.2.

** A brief, general summary of the ESECA is presented under Siting Objective 2.

- Developing or revising national SO_2 control policies; e.g., new source performance standards (NSPS), tall stacks, and supplementary control systems (SCS) (use 6).

- Supporting enforcement actions (use 9), including SCS surveillance.

- Reviewing new sources (use 4). In this case, the data would be used to provide urban background concentrations at the point of maximum concentration contributed by a proposed new source or at any other point in the major impact area at which the NAAQS may be threatened.

- Providing information to the public, etc. (use 12).

2.3.3 Siting Objective 3 - Determination of the Impact of Isolated Point Sources

This siting objective is similar to Objective 2. Because there will be few, if any, interfering sources in rural areas, area diffusion modeling need not be employed for locating monitoring stations or in data interpretation. However, because of special problems associated with locating maximum impact points from individual sources in rural areas, mobile sampling may be required, particularly in regions of complex terrain. Only the 3-hour and 24-hour average concentrations need to be considered since the annual standard will not likely be contravened by an individual isolated point source.

The primary data uses related to this siting objecitve are the same as those associated with Siting Objective 2, particularly SCS implementation and surveillance. Other uses include establishing baseline air quality levels for PSD planning (use 5) and impact assessments associated with the enforcement of PSD policies.

2.3.4 Siting Objective 4 - Assessment of Interregional SO_2 Transport

Transport or advection of pollution across state or other jurisdictional boundaries received considerable attention in the development of some SIP's (e.g., Ball, et al., 1972). Large urban areas situated near or straddling state boundaries can result in a considerable exchange of SO_2 between the affected states--e.g., New York/New Jersey/Connecticut (New York City); Pennsylvania/New Jersey (Philadelphia); Missouri/Illinois (St. Louis); and Illinois/Indiana (Chicago). A rather detailed study of interstate transport of SO_2 was conducted by the NAPCA in the New York/New Jersey area (DHEW, 1967).

The EPA has acknowledged the existence of these situations and has required their being taken into account in state SIP's. The main objective of monitoring interregional transport of SO_2 is to assess the relative impacts in adjoining states. This assessment can provide information to the air pollution control agencies of these states for refining or optimizing control measures for achieving and maintaining the NAAQS (uses 2 and 3).

In certain situations, monitoring sites set up to monitor incoming SO_2 may also be considered as sites for measuring background concentrations and determining base concentrations for environmental impact studies, AQMP and PSD planning (uses 5 and 12).

2.3.5 Siting Objective 5 - Determination of Base Concentrations in Areas of Projected Growth

The air quality maintenance provisions of the Clean Air Act require that once the NAAQS are attained they must be maintained thereafter. To effectuate this requirement, a series of guideline documents was prepared and issued to the states (EPA, 1974a) to assist them in establishing Air Quality Maintenance Areas (AQMAs), and preparing AQMPs. Volume XI of the series ("Air Quality Monitoring and Data Analysis") addresses rather specifically the air monitoring requirements of AQMPs. The basic requirement involves the design and operation of a monitoring network (or a modification of an existing network) to establish baseline concentration levels from which air quality levels are projected into the future. Ongoing air quality measurements are then matched against projected levels to ascertain AQMP effectiveness. This siting objective satisfies the air monitoring requirements of AQMP development. Data originating from monitoring stations satisfying this siting objective will be particularly relevant to the activities of city/regional planners and air quality policy/decision makers associated with such programs and the preparing of environmental impact statements (uses 5 and 12).

2.3.6 Siting Objective 6 - Initiation of Emergency Episode Abatement Actions

States have established (with EPA guidance) air quality levels at which preplanned abatement strategies must be activitated for precluding air pollution buildup during air stagnations. These plans are usually "triggered" on the basis of real-time monitoring information from appropriately located sites.

Episodal concentrations often represent the highest short-term concentrations ever observed during the year in any given area. The highest peaks occur in the urban core, but are also relatively high and generally uniformly distributed over the areas surrounding the urban core. Since episodes are of relatively short duration (maximum duration of about three days or so), the acute effects on human health and public welfare are of greatest concern.

Most emergency episode plans drawn up by the states provide for a four-stage abatement mechanism. In each successive stage, more stringent emission limitations are imposed on prespecified sources to deal with the pollution buildup in a stepwise manner. The air quality situation is continuously monitored and each stage (and the eventual "all clear") is triggered according to prespecified criteria. Sites established for SO_2 monitoring during air stagnations should use continuous type instruments that output directly (via telemetering) to the air pollution control agency office (and computer) to facilitate rapid data acquisition and evaluation. In most situations, the site should be located in the very heart of the maximum SO_2 emission density zone of an urban area, since during air stagnation conditions wind speeds are low and directions are variable so the maximum concentration should occur near to where the emission density is a maximum. Since it is desirable to maximize monitoring coverage during a stagnation episode, other sites can be used to trigger the episode abatement plan and/or to monitor the progress of each stage. Most often these will be the peak concentration stations and other stations located in the urban area. The relevant data uses here are, therefore:

- Documenting episodes and initiating episode controls (use 10).
- Providing public information via air pollution indices (use 12).

2.3.7 Siting Objective 7 - Assessment of Background Concentrations in Rural Areas

Background levels of SO_2 in rural areas represent the lowest levels, or the approximate lowest levels (depending on the degree of interregional SO_2 transport) attainable over a large region. They may be considered as the baseline concentrations near urban areas that should be known in order to optimize the degree of control necessary to attain and maintain the NAAQS over the urban area. This siting objective is also closely related to Siting Objectives 4 and 5; in fact, several of these objectives could be satisfied with one site strategically located. The data uses relevant to this siting objective include uses 2, 3, 5 and 12.

2.3.8 Siting Objective 8 - Determination of Population Exposure

Since the primary purpose of the NAAQS is to protect human health, SO_2 monitoring sites should be located in areas characterized by high population density to ascertain the degree of SO_2 exposure to large numbers of people. In most cases, these areas will be the residential areas of cities adjacent to the central business districts (CBDs) and the peripheral suburbs.

In these areas, SO_2 concentrations for the three averaging times may be relatively high. However, the greater spatial variability of the shorter term peaks shifts the major concern to the annual average concentrations where effects on people are most likely to be chronic. This siting objective places the emphasis on the monitoring of SO_2 where most people live (constant exposure to relatively high levels) rather than where they work, which is covered by Siting Objective 1. The relevant data uses are then:

- Documenting population exposure and health research (use 11).
- Providing information to the public via air pollution indices (use 12).

2.3.9 Siting Objective 9 - Diffusion Model Calibration and Refinement

The calibration and refinement of diffusion models is becoming one of the most important objectives of air monitoring (use 7). In fact, many of the objectives described in this section may well, ultimately, be satisfied by the operation of appropriate diffusion models.

Many states used diffusion models to develop control strategies (e.g., Morgenstern and Hagg, 1972) to satisfy EPA SIP requirements. Diffusion modeling by state agencies is expected to continue as an ongoing activity in refining and/or optimizing control strategies and in providing a development/assessment tool in the design and implementation of AQMPs and PSD plans.

A realistic SO_2 model calibration program may require the establishment of a special, temporary network of SO_2 monitors to facilitate spatial as well as temporal correlation studies. For a detailed discussion on the problems of model calibration, see Brier (1973, 1975). Monitoring sites established for other objectives may also be used to supplement data from the special network.

Diffusion models are of two basic types--Gaussian and grid. Gaussian models simulate individual plumes (continuous or puff) by assuming a Gaussian distribution of plume material in the crosswind and vertical dimensions. Grid models, on the other hand, compute mean concentrations for each cell of a three-dimensional matrix of cells. There are several varieties of grid models, one of which is the full-airshed Eulerian (fixed-cell) type.

Several problems are associated with each type of model. A major problem with the Gaussian models, particularly the continuous versions, is their inability to account for complex air flows in which SO_2 source plumes are imbedded (e.g., in urban areas and in other regions of complex terrain). Grid models, however, are difficult to validate because their volume-averaged predictions must be compared to measurements taken at a point. Neither type of model can simulate the effects of micro-scale features of complex flows.

The largest air pollution study ever conducted by the EPA is presently underway in St. Louis, Missouri. The Regional Air Pollution Study (RAPS) has been referred to as the modeler's model. Models have been developed for simulating emissions, meteorology, photochemical reactions, removal processes, etc. Twenty-five air monitoring stations have been established in and around St. Louis for the primary purpose of model validation (Pooler, 1974). All five primary air pollutants and selected meteorological variables will be measured. Each site was carefully chosen in order to prevent contamination from small local sources, dust re-entrainment from the ground, and the measurement of anomalous winds.

Model calibration and refinement work is very highly specialized. Network configurations, instrument specification, characteristics, and other factors all reflect monitoring requirements that are probably unique for any given project. It is difficult to anticipate the monitoring requirements of such projects and impossible to generalize related siting guidelines. An attempt to do so was considered beyond the scope of the objectives of routine monitoring which this report addresses. However, it may be safely stated that ambient data from any source could probably be utilized, to at least a limited extent, in model calibration/validation studies if the conditions under which such data was obtained were known (and documented).

3.0 SPECIAL CHARACTERISTICS ASSOCIATED WITH SO_2 MONITORING

Because of the complex relationships among geographic, topographic, and climatologic factors; SO_2 patterns; and the various averaging times of the NAAQS; the selecting of appropriate sites for SO_2 monitoring can be a very complex process. However, the process can be simplified somewhat by first viewing the various siting objectives in the context of an SO_2 monitoring "universe". Then, through an elimination, consolidation and optimization process, one can establish various site types such that each can be associated with a general siting approach. Initially, it was expected that each site type could be related to a specific siting procedure. However, because of the nature of SO_2 concentration patterns, the requirements of some of the siting objectives, data uses and other factors, this was not possible in many cases. As will be seen in Section 4.0, some procedures are more closely related to the siting objective than site type.

The major objective of this section is to discuss the elements of the universe. This includes spatial scales of representativeness and how these relate to the averaging times of the NAAQS and the nature of urban concentration patterns, terrain characteristics, meteorology, land use, and other elements. Such a discussion will constitute an appropriate introduction to Section 4.0 (which presents the site selection procedures) by providing the site selector a basis for understanding some of the characteristics and problems associated with SO_2 monitoring.

3.1 MONITORING NETWORK CONCEPTS

It might be appropriate to begin this section with some historical perspective of monitoring in general by discussing the two basic types of monitoring networks. Many of the networks of the recent past and several existing ones are typified by these types.

3.1.1 Target Networks

Target networks are source-oriented in that each monitoring site has a specific and unique objective associated with it (e.g., see Stockton, 1970). These objectives may include the assessment of the air quality impact of a specific large source or the combined impacts of many sources in a particular area (usually where the maximum concentration occurs). The main concept behind the target network is that if an objective of a control or surveillance strategy is achieved at a maximum concentration point, then they are achieved in all areas of the affected region. Such a network requires a minimum number of site locations, and for this reason they are often considered optimum networks. This optimization also allows for a greater degree of sophistication regarding instrument types and data acquisition systems.

3.1.2 Area Networks

Prior to the general availability of diffusion models, initial urban air quality surveys were often conducted via an area network where large numbers of monitors were uniformly spaced over a region, usually at each point of a grid. The concepts behind this approach were that the more samples one had in the field, the more likely the concentration pattern characteristics of interest would be revealed, or the more accurately the regional average concentration could be computed. The earlier networks of this type were often established for purposes of research (e.g., see Keagy, et al., 1961). Because of the large number of sites, network maintenance was costly, and the use of expensive, high quality instruments was prohibitive. However, usually after a year or so of experience, one could drastically reduce the number of stations and still achieve all monitoring objectives with a reasonable degree of confidence (as discussed by Herrich, 1966). In a sense, the area network was gradually converted to a quasi-target network.

Area or quasi-target networks have been established in several large metropolitan areas where large sections are characterized by uniform land use such as large residential and commercial areas. In these situations, site locations are often determined on the basis of population and geographical coverage (e.g., see Heller and Ferrand, 1969).

There are some interesting variations of the area network type. Some may be configured on the basis of the orientation of a major topographical feature such as a river valley; others, on the location of a large emission district embedded in a larger, more diffuse emission region. In these situations, individual sampling sites may be located at points along a series of concentric arcs centered on the high emission district (e.g., see Leavitt, et al., 1957; Rossano, 1956) to "normalize" the distance-concentration factor, or at points along a series of lines perpendicular to the valley axis to ascertain concentration flux at each line. Other sites may be located to measure air quality upwind and downwind of the region.

For the routine uses of SO_2 monitoring data, the characteristics of an ideal SO_2 monitoring network should incorporate the desirable characteristics of both network types.

3.2 SPATIAL SCALES OF REPRESENTATIVENESS

Much of the discussion in this section was stimulated by a recent report by Ludwig and Kealoha (1975)--a counterpart report to this one for carbon monoxide monitoring. Since the scales of measurement as presented in that report are directly applicable to SO_2 (or to any pollutant) measurement scales, they are presented below but restated in terms applicable to SO_2 monitoring.

The volume of air sampled by an SO_2 instrument is very small when compared to the volume of air that the resulting air quality reading is supposed to represent (up to tens of thousands of km^2). It is not possible for a single monitor to sample all of the air volume over the area of interest to produce the number which is the actual average air quality reading for the area. Ideally, the monitor must be placed such that the air quality of the small sampled volume is representative of the air quality over the entire area of interest or reasonably so. (This requirement implies a certain degree of homogeneity over this area which is not always met, however.) The size of this area of interest establishes a corresponding spatial scale of representativeness over which one would like the measurement to apply.

The typical spatial scales of representativeness associated with most SO_2 siting objectives and related data uses are illustrated schematically in Figure 3-1 and discussed below, sequentially, from the smallest scale. In some situations, there are special problems associated with the representivaness of some SO_2 measurements; these problems are discussed in Section 3.2.1.

- Microscale. Ambient air volumes with dimensions ranging from meters up to about 100 meters are associated with this scale. Studies of the distribution of SO_2 within plumes either over flat or complex terrain or within building wake cavities require measurements of this scale. The development of special models designed to simulate such small scale SO_2 distributions also require microscale measurements for model verification and refinement.

- Middle Scale. This scale represents dimensions of the order from about 100 meters to 0.5 kilometer and characterizes air quality in areas up to several city blocks in size. Some data uses associated with middle scale measurements include assessing the effects of control strategies to reduce urban peak concentrations (especially for the 3-hour and 24-hour averaging times) and monitoring air pollution episodes.

- Neighborhood Scale. Neighborhood scale measurements would characterize conditions over areas with dimensions in the 0.5 km to 4 km range. As will be discussed later, this scale applies in areas where the SO_2 concentration gradient is relatively flat--mainly suburban areas surrounding the urban center--or to large sections of small cities and towns. In general, these areas are quite homogeneous in terms of SO_2 emission rates and population density. Neighborhood scale measurements may be associated with baseline concentrations in areas of projected growth and in studies of population responses to exposure to SO_2 (or health effects). Also, concentration maxima associated with air pollution episodes may be reasonable uniformly distributed over areas of neighborhood scale, and measurements taken within such an area would represent neighborhood as well as middle scale concentrations.

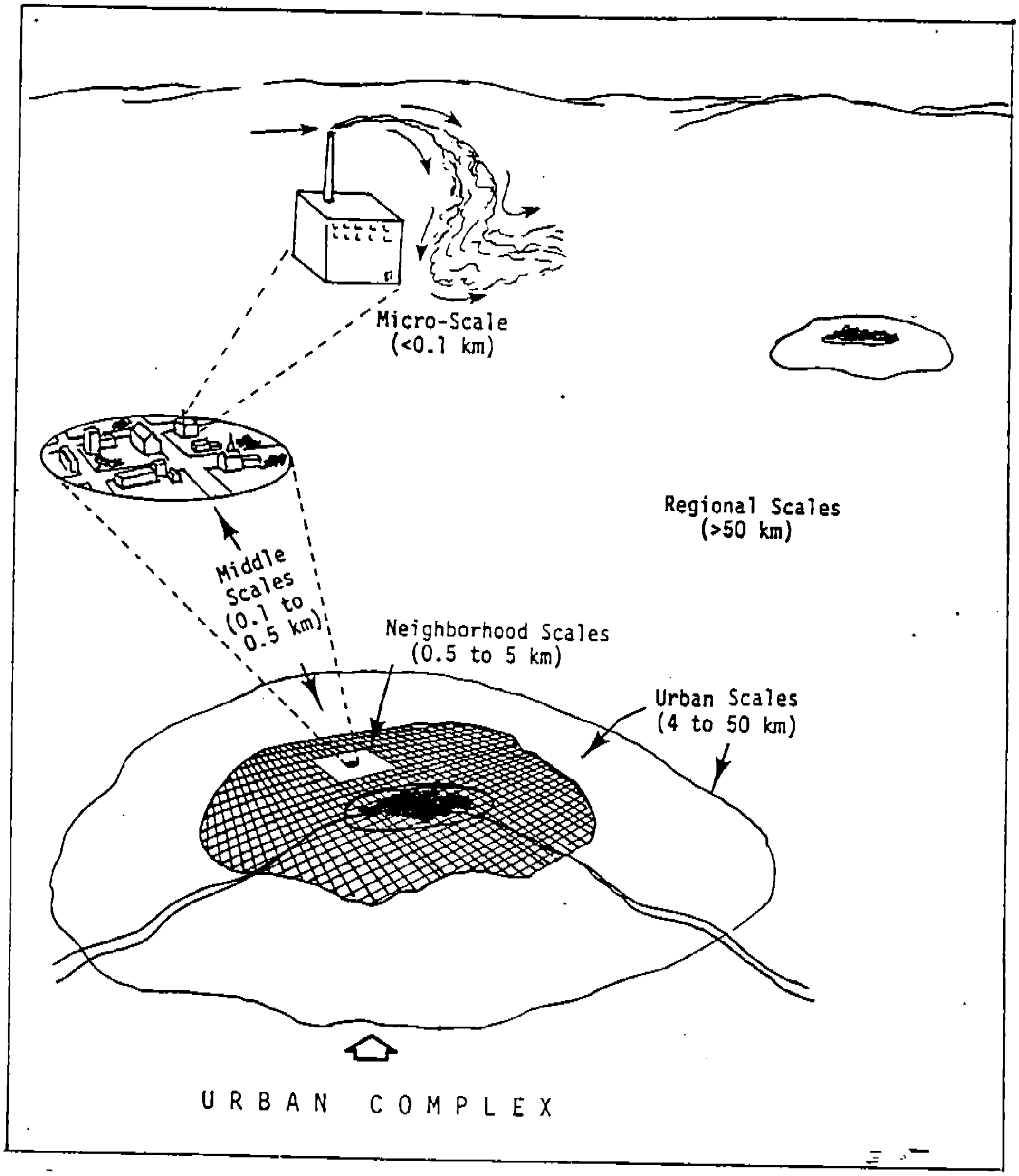

FIGURE 3-1. Illustration of various spatial scales of representativeness.

- Urban Scale. Urban scale measurements would be made to represent conditions over areas with dimensions on the order of 4 to 50 km. Such data could be used for the assessment of air quality trends, the effect of control strategies on urban scale air quality.

- Regional Scale. Conditions over areas with dimensions of as much as hundreds of kilometers would be represented by regional scale measurements. These measurements would be applicable mainly to large homogeneous areas, particularly those which are sparsely populated. Such measurements could provide information on background air quality and interregional pollutant transport.

- National and Global Scales. These measurement scales represent concentrations characterizing the nation and the globe as a whole. Such data would be useful in determining pollutant trends, in studying international and global transport processes, and in assessing the effects of control policies on national and global scales.

3.2.1 Measurement Scales Relevant to SO_2 Monitoring

In SO_2 monitoring, a distinction should be made between the spatial scale desired to be represented by a single measurement and the spatial scale actually represented by that measurement. The former is determined by the size of the area of interest which is associated with the intended use of the data and associated siting objective, while the latter is a function of the spatial variation of concentration in the horizontal over the area of interest. This variation results not only from the impacts of local sources within the area, but, more importantly, from the collective impacts of all sources located outside of the area of interest. These collective impacts result in background concentration patterns and gradients over the area of interest that essentially dictate the spatial scale that will be represented by a single measurement taken at a station located anywhere in that area. This dilemma may be stated in another way--the distance from a monitoring station at which measurements become significantly different from those at the monitoring station determines the spatial scale represented by measurements at the monitoring station. This distance is a function of the background concentration gradient. SO_2 concentrations over urban areas generally decrease rapidly outward from a peak near the urban center, and rather smoothly for annual averaging times (e.g., see Larsen, et al., 1961; and Figure 2-3, Stern, et al., 1973) as shown in Figure 3-2. Also, superimposed on the relatively smooth concentration pattern are "bumps"* due to large point sources. Hence, SO_2 concentrations in cities are, in general, neither uniform over large, homogeneous land use areas within the city, nor are they contained within numerous individual independent cells or street canyons as is the case for carbon monoxide (c.f., Figure 3, Ott, 1975).

Because of this nature of SO_2 distributions over urban areas, the middle scale is the most likely scale to be represented by a single measurement in an urban area, and only if the undue effects from local sources (minor or major point sources) can be eliminated. Neighborhood scales would be those most likely to be represented by single measurements in suburban areas where the concentration gradients are less steep. Regional scale measurements would be

* For shorter averaging times these bumps become large "spikes" superimposed on a greatly irregular background pattern.

associated with rural areas. Microscale measurements may be required in certain situations. For example, in monitoring the impact of an isolated point source in complex terrain, initially it may be desirable to use mobile sampling or to establish a dense, area-type network to determine the general location of the maximum impact point. This will provide guidance for locating permanent sites for measurements representing the more relevant middle scale. Normally, investigators making such microscale measurements have specific siting requirements that reflect the specific and often unique purposes of their projects; these requirements would be difficult to generalize.

Because of the great variation of SO_2 concentrations in urban areas, it is unlikely that urban scale concentrations could be measured at a single site.

National and global scale concentrations are not of sufficient interest to state and local agencies to justify specific treatment. However, concentrations characterizing areas on these scales may be estimated by synthesizing regional, and then national scale measurements.

Figure 3-2 shows relative locations of sites in an urban area for measuring concentrations representing several spatial scales of measurement.

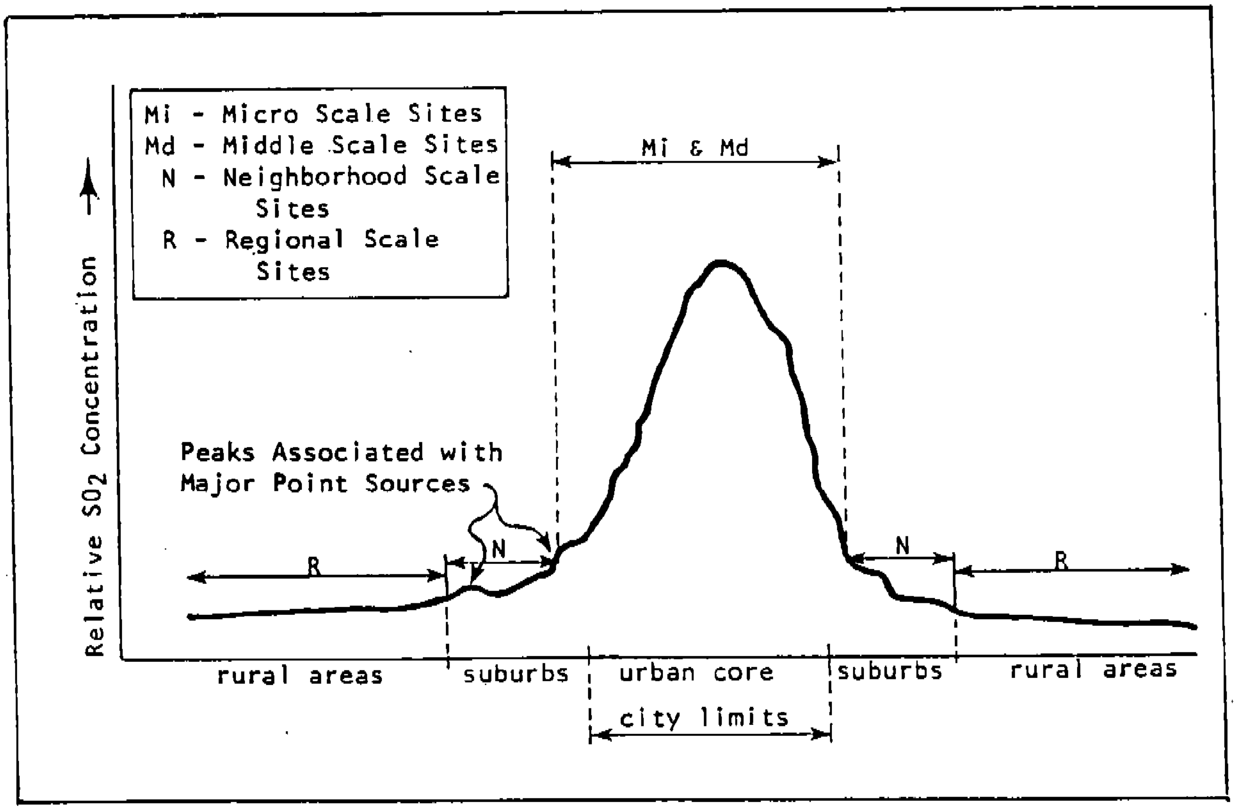

FIGURE 3-2. Relative locations of sites for measuring concentrations representing several spatial scales of measurement in an urban complex, with respect to annual averaging times.

3.3 MONITORING SITE TYPES AND ASSOCIATED SITING OBJECTIVES AND DATA USES

Our survey of the literature indicated that SO_2 monitoring sites can be classified as either proximate or general level. Proximate sites are those associated with siting objectives that require information regarding impacts from a specific source or a group of specific sources. These sources may be isolated, such as a smelter complex in a remote area, or a power plant so located in a city that it constitutes a large fraction of the total observed SO_2. General-level sites are those located in areas where the total concentration is important but contributions from individual sources to that concentration are relatively unimportant.

The siting objectives and related data uses and their associated site types and spatial scales of representativeness are summarized in Table 3-1. Blank spaces indicate those scales of measurement that are either inconsistent with the siting objective, or are simply not very useful. Proximate site types are indicated by "Pr" and general level by "GL". The underlined Xs indicate the desired spatial scale to be represented by a single measurement. The remaining Xs indicate other spatial scales that may actually be represented by a single measurement (because of the conditions imposed by the background concentration gradients). The letters (P) and (F) within the site type column indicate whether the siting objective is concentration pattern oriented or is associated with a fixed geographical area independent of the SO_2 pattern. For example, an urban peak concentration site (P) will be located as close as possible to the peak concentration point in the city without regard to the geographical setting of the siting area, while a site established to determine base concentrations in areas of projected growth (F) will be located within the growth area regardless of the characteristics of the prevailing SO_2 concentration pattern. It also might be worthwhile here to mention that the less complicated the source mix and density (i.e., as one approaches rural conditions) the wider the range of spatial scales a reading will represent; for example, in a homogeneously rural area, an individual reading will represent all spatial scales ranging from micro to regional and over any averaging time.

3.4 THE SO_2 MONITORING UNIVERSE

In the foregoing discussions, we have identified the uses of SO_2 data and their relationships to specific monitor siting objectives; we have also related the individual siting objectives to appropriate spatial scales of representiveness (see Table 3-1). However, there are other variables that must be considered in the site selection process--namely the averaging times of the NAAQS and the land use and topographical settings. All combinations of the above variables that must be accounted for in the selecting of monitoring sites, and to a certain extent, in determining probe exposure and monitoring mode, constitute an SO_2 monitoring "universe". It is from this universe that specific site types are selected to which are attached specific site selection procedures.

The five basic variables (the first two have already been discussed) that constitute the SO_2 monitoring universe are listed following Table 3-1.

TABLE 3-1

Relationships Among Siting Objectives and Related Data Uses, Site Types, and Scales of Representativeness

(a) If the assumption is made that the peak concentration point will only rarely occur (within middle-scale limits) at the monitoring site, then the reading will better represent typical maximum values on the neighborhood scale in the maximum impact area.

(b) Microscale measurements may be required to define plume structure via either area network or mobile sampling to simulate plume or to estimate permanent middle scale site locations.

(c) Under stagnation conditions, the maximum concentration zone will probably expand in area, in which case the reading may represent neighborhood scale averages as well as middle scale averages.

(d) Because of the multitude of scales on which models are designed to simulate air pollution, data on any scale may be required in model calibration/refinement work.

* The "Spatial Scale of Representativeness" is keyed as follows: I - microscale; II - middle scale; III - neighborhood scale; and IV - regional scale.

Siting Objectives/ Data Uses	Site Type	Spatial Scale of Representativeness*			
		I	II	III	IV
1. **Determination of Peak Concentrations in Urban Areas.** Judging attainment/maintenance of NAAQS. Evaluating progress in achieving/maintaining of NAAQS. Developing/revising SIPs/evaluating control strategies. Providing data to facilitate the ESECA of 1974. Supporting enforcement actions. Public information.	GL (P)		(a)X	X	
2. **Determination of the Impact of Individual Point Source in Multi-Source Urban Setting.** Developing/revising SIPs/evaluating control strategies. Reviewing new sources. Developing/revising national SO_2 control policies(NSPS,SCS, tall stacks). Providing data to facilitate ESECA of 1974. Supporting enforcement actions.	Pr (P)		X		
3. **Determination of the Impact of Isolated Point Sources.** Developing/revising SIPs/evaluating control strategies. Reviewing new sources. Developing/revising national SO_2 control policies(NSPS,SCS, tall stacks). Providing data to facilitate the ESECA of 1974. Supporting enforcement actions.	Pr (P)	(b)X	X		
4. **Assessment of Interregional SO_2 Transport** Establishing baseline air quality levels for PSD planning and AQMP. Evaluating progress in achieving/maintaining NAAQS. Developing/revising SIPs to attain/maintain NAAQS. Public information.	GL (P)				X
5. **Determination of Base Concentration in Areas of Projected Growth.** Establishing baseline air quality levels for PSD planning and AQMP. Evaluating progress in achieving/maintaining NAAQS. Developing/revising SIPs to attain/maintain NAAQS. Public information.	GL (F)		X	X	X
6. **Emergency Episode Abatement Initiation and Monitoring.** Documenting episodes and initiating episode controls Public information.	GL (P)		X	(c)X	
7. **Assessment of Background Contration in Rural Areas.** Establishing baseline air quality levels for PSD planning and AQMP. Developing/revising SIPS to attain/maintain NAAQS. Public information.	GL (P)				X
8. **Determination of Population Exposure in Populated Areas.** Documenting population exposure and health research. Public information.	GL (F)		X	X	X
9. **Diffusion Model Calibration and Refinement. (d)**	GL Pr (P)	X X	X X	X	X

1) Site Type

Proximate
General Level

2) Spatial Scale of Representativeness

Microscale
Middle Scale
Neighborhood Scale
Regional Scale

3) Averaging Time of NAAQS

3-hour (second highest)
24-hour (second highest)
Annual

4) Land Use Setting

Urban
Suburban
Rural

5) Topographical Setting

Coastal
Ridge-valley
Interior Plain
Rugged, Irregular (interior)
Rugged, Irregular (coastal)

Only a portion of the monitoring universe is presented in Figure 3-3 which shows only 15 combinations of variables. For the entire universe, the combinations total 360. Each combination could theoretically require a unique set of siting procedures depending on the siting objective, data use, and the commonality and availability of meteorological data for the various combinations. However, it will be seen that the combinations of these universe elements that reflect the stated siting objectives can be accommodated by a relatively small number of site types.

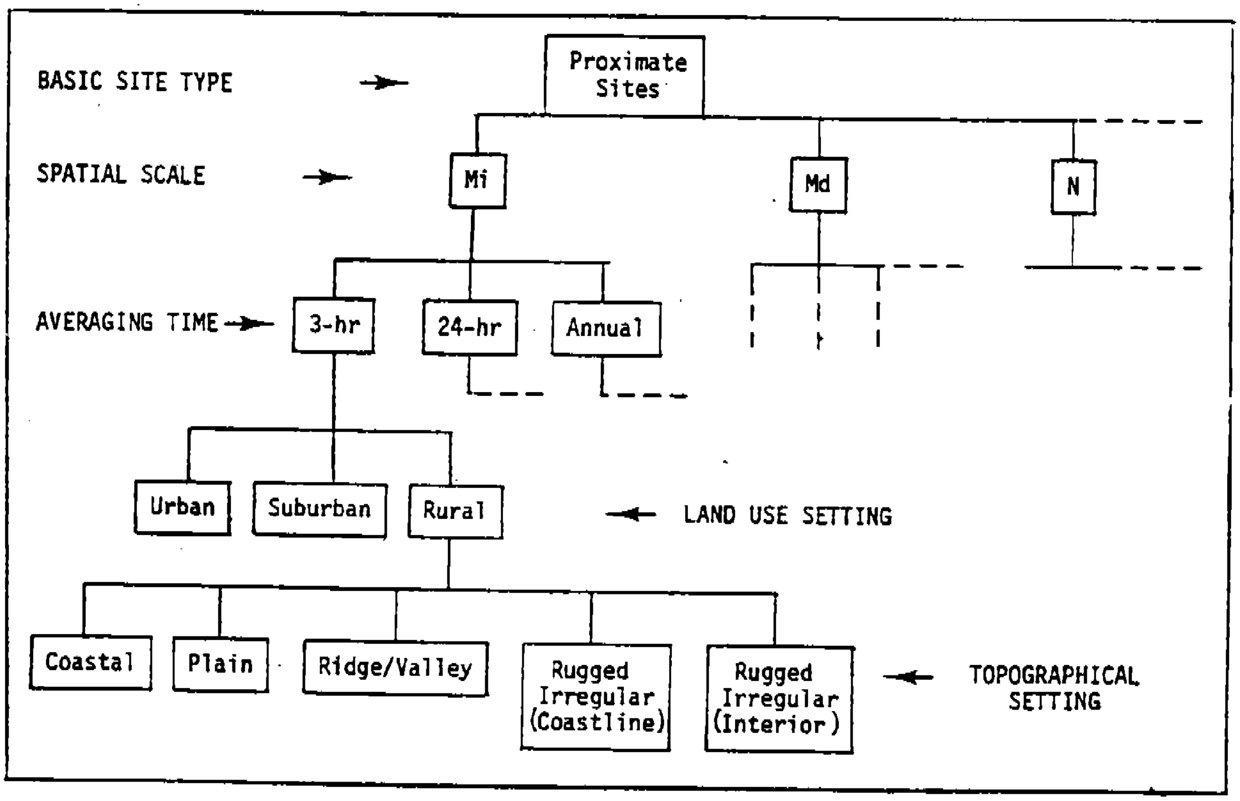

FIGURE 3-3. Portion of SO_2 monitoring universe.

3.5 THE FIVE RELEVANT MONITORING SITE TYPES

The concept of the monitoring universe as presented above can be converted to more convenient tabular format. Tables 3-2 and 3-3 show the resulting universe after considering only the elements of Table 3-1, and the desirable spatial scale to be represented by a single measurement. For example, an SO_2 reading representing a regional 3-hour mean concentration associated with an isolated point source either does not exist or is irrelevant. From Table 3-2, all siting objectives can be accommodated by five monitoring site types:

1) General Level, Regional Scale.

2) General Level, Neighborhood Scale.

3) General Level, Middle Scale.

4) Proximate, Middle Scale.

5) Proximate, Microscale.

TABLE 3-2

Relationships Among Table 3-1 Elements and Associated Relevant Averaging Times

SITING OBJECTIVES	Basic Site Type	Averaging Time 3-hour	Averaging Time 24-hour	Averaging Time Annual
1	Pr			
	GL (P)	Md	Md	Md
2	Pr (P)	Md	Md	Md
	GL			
3	Pr (P)	Mi,Md	Mi,Md	*
	GL			
4	Pr			
	GL (P)	R	R	R
5	Pr	**		
	GL (F)		N	N
6	Pr			†
	GL (P)	N	N	
7	Pr			
	GL (P)	R	R	R
8	Pr	‡		
	GL (F)		N	N
9	Pr (P)	Mi,Md	Md	Md
	GL (P)	Mi,Md, N,R	Md, N,R	Md, N,R

KEY

Mi - Microscale.

Md - Middle Scale.

N - Neighborhood Scale.

R - Regional Scale.

Pr - Proximate.

GL - General Level.

(P) - Pattern Oriented Site.

(F) - Fixed Geographically Oriented Site.

* Not likely for an isolated point source.

** Difficult to estimate since no specific source is impacting.

† No episodes occur in this time scale.

‡ Secondary standard; no significant effects.

TABLE 3-3

Matrix of Topographical and Land Use Types

	Topographical Type (A, B, C, D, E)				
Land (U)	A,U	B,U	C,U	D,U	E,U
Use (S)	A,S	B,S	C,S	D,S	E,S
Type (R)	A,R	B,R	C,R	D,R	E,R

KEY

U - Urban
S - Suburban
R - Rural
A - Coastal
B - Plain
C - Ridge/Valley
D - Rugged, Irregular, Interior
E - Rugged, Irregular, Coastal

Each of these site types is associated with a basic procedural siting approach with variations from the basic approach being functions of the siting objective, averaging time, and physical setting.

It would be appropriate at this point to summarize the material presented in this section by showing an example of the process that ties the site type to the intended use of the data. This can be accomplished in a stepwise manner as follows:

a) Decide the use to which the data will be put.

EXAMPLE: Providing data to implement the provisions of the ESECA of 1974.

b) Determine all siting objectives that will satisfy the data use.

From Table 3-1, siting objectives 1, 2, and 3 will satisfy the proposed use of the data.

c) From Table 3-2, determine the site type and averaging times of concern that apply to each siting objective.

SITING OBJECTIVE 1: General-Level, Middle-Scale, all averaging times.

SITING OBJECTIVE 2: Proximate, Middle-scale, all averaging times.

SITING OBJECTIVE 3: Proximate, Middle and/or Microscale 3-hour and 24-hour averaging times.

d) From Table 3-3, determine the physical setting of the siting area. There are 15 combinations of physical settings that are relevant to the SO_2 monitoring site selection process.

The specific siting procedures associated with each site type are presented in the next section.

4.0 SITE SELECTION PROCEDURES AND CRITERIA

Procedures and criteria for selecting specific monitoring site locations and instrument inlet exposures have been developed for the relevant monitoring site types and are presented in this section. They are generally uniform for each siting objective associated with a given site type. It was not possible to develop specific siting criteria to satisfy some siting objectives (e.g., isolated point source monitoring in extremely rough or mountainous terrain). In these instances, general guidelines addressing "points to consider" are presented.

The site selection process itself is an elimination process; general siting areas are selected, then specific prospective sites within the areas are gradually eliminated in accordance with specific criteria until a small subset of acceptable sites remains. The final selection is made from this subset.

It should be made clear at this point to state that not every AQCR is required to have each type of monitoring site described in this section; the types of sites required would depend on the nature of the SO_2 problems in the AQCR. These are judgements to be made by the control agency or site selector.

The organization of much of this section is based on that of the report by Ludwig and Kealoha (1975)--essentially flow charts showing the basic structure and flow of the procedural logic followed by discussion of the elements of the flow chart. Much of the material is presented without discussion of the justification or rationale for the various steps of the procedures; this is reserved for Chapter 5.0 to maintain the clarity and continuity of the procedures as discussed here.

4.1 DESCRIPTION OF SITE SELECTION AIDS AND BACKGROUND MATERIAL

An integral part of the site selection process is the acquisition and/or development of background material, data, and, in some situations, the use of auxiliary equipment (e.g., portable wind station). Such material is needed to provide the site selector with information mainly regarding the physical characteristics of the siting area. This information may include the terrain and land-use setting of the prospective monitor siting area, the proximity of large water bodies, the distribution of SO_2 sources in the area, the location of appropriate National Weather Service (NWS) airport stations from which weather data may be obtained, etc. Depending on the siting objective, this material may take the form of:

- Isopleth maps SO_2 air quality,
- Emissions inventories,
- Meteorological data,
- Wind roses,
- Portable wind equipment,
- Topographic/population/land-use maps, and
- Mobile sampling equipment.

The purpose of each item will be described briefly below prior to the presentation of the site selection procedures. A more complete discussion of this material and its sources can be found in the appendices and in Section 5.0.

Isopleth maps, particularly those generated by diffusion models is recommended for use in determining the general location of a prospective monitoring site, or a prospective siting area within which the final site is to be selected. For siting monitors in urban areas, multi-source models such as the Air Quality Display Model (AQDM) are recommended. For isolated point source monitoring in relatively uncomplicated terrain, various point source models (PTMPT, PTDIS, PTMAX; see Appendix E) or graphical solutions of the Gaussian point source equation are suggested. (It will be seen that the guidelines presented herein are strongly diffusion-model-output oriented.)

Emission inventory information for point sources is available from the U.S. Environmental Protection Agency (EPA) for any area of the country for annual and seasonal averaging times. Specific information characterizing the emissions and large point sources for the shorter averaging times (diurnal variations, load curves, etc.) can often be obtained from the source. Area source emission data by season, although not available from the EPA, can be generated by apportioning annual totals according to degree days. This kind of information provides some of the input to the diffusion models and are also important for other reasons that will be discussed later.

The nature of the elements of Table 3-3 in Section 3.0 determine the meteorological and diffusion parameter input to the diffusion models. In most cases, the meteorological data originating from the most appropriate (not necessarily the nearest) NWS airport station in the vicinity of the prospective siting area will adequately reflect conditions over the area of interest, at least for annual and seasonal averaging times. In developing data in complex meteorological and terrain situations, diffusion meteorologists should be consulted. A complete list of NWS stations that can provide most of the relevant weather information in support of siting activities anywhere in the country can be found in Appendix A. Such information includes joint frequency distributions of winds and atmospheric stability (stability-wind roses). These are provided by the output of the National Climatic Center "STAR" computer program. For the shorter averaging times or in complex terrain situations, the use of portable wind equipment, smoke bombs, time-lapse photography may be necessary. Land use types and topographical characteristics of specific areas of interest can be determined from U.S. Geological Survey (USGS) and land use maps. Detailed information on urban physiography (building/street dimensions, etc.) can be obtained from Sanborn maps (see Appendix D). Additional information may have to be obtained by visual observations, aerial photography, and surveys to supplement that available from the above sources. Such information may be required to determine the appropriate diffusion coefficients and SO_2 half-life values to be used by the models as well as determining the locations of local sources in and around the prospective siting areas.

Finally, after the general location of a site or prospective siting area has been established, mobile sampling may be required to determine the optimum site location, particularly in regard to isolated point source monitoring (see Appendix C).

4.1.1 The Critical Role of Diffusion Modeling in the Site Selection Process

As discussed in Section 3.2.1, the SO_2 background concentration gradient over an area essentially determines the spatial scale represented by measurements taken at a single station located in that area. Also, it was seen that in Section 3.3 that some siting objectives may be associated with specific features of the SO_2 pattern while others may be associated with fixed geographical areas that are independent of such features. Since the only objective means of obtaining such gradients and patterns is by diffusion modeling, the modeling of the area of interest will usually be a prerequisite for selecting monitoring sites.

In Sections 4.1.1 and 4.1.2 below, the role of diffusion models in the site selection process is discussed in general terms to orient the reader. The model's role in the selecting of sites to satisfy specific siting objectives is discussed in more detail later in the appropriate sections.

4.1.1.1 Siting Objectives Associated with Fixed Geographical Areas

For siting objectives associated with fixed geographical areas (see Table 3-1), measurements from a single monitoring station within such an area can represent concentrations over any spatial scale. In a given scenario, the particular spatial scale represented would depend directly on the background concentration gradient prevailing over the area of interest. In developing the siting criteria in these situations, we arbitrarily chose specific concentration gradients that we felt appropriately characterized the various spatial scales (see Section 5.3.3 for rationale) as follows:

1) If the concentration gradient over the area of interest does not exceed about 0.5 $\mu g/m^3$-km, the measurements from a single site will represent concentrations over regional spatial scales.

2) If the concentration extremes over the area of interest are not within about 25% of the mean value, then more than one site is required to represent concentrations over the area. To establish the number of stations, the area is divided into the number of

parcels required to bring the extreme concentrations over each parcel to within 25% of the mean of each parcel. Measurements from single sites located near the center of each parcel should adequately characterize the concentration over that parcel. The spatial scales represented by the measurements will be the same as the spatial scales of the parcel, namely neighborhood (0.5 to 4.0 km) or middle (0.1 to 0.5 km) scales.

4.1.1.2 Siting Objectives Associated With Features of the SO_2 Pattern

The peak SO_2 concentration is usually the most important feature considered for siting objectives associated with features of the SO_2 pattern (see Table 3-1). The peak concentrations may be due to either single or multiple sources. The diffusion model is used to determine the approximate location of the peak and can consider annual patterns as well as near worst case 3-hour and 24-hour patterns. Because the concentration gradient in the vicinity of the peak is often steep and/or irregular, the middle scale is the most likely scale to be represented by measurements from a single station located near the peak.

The use of models to aid in determining regional scale site locations in rural areas is optional. In these situations, the model is used to verify that the prevailing concentration gradient is relatively flat.

4.2 GENERAL-LEVEL REGIONAL-SCALE STATIONS

Figure 4-1 shows the recommended procedure siting objectives for establishing general-level regional stations. There are two basic siting objectives for which regional stations are established: (1) to measure regional mean background concentrations; and (2) to assess pollutant transport.

The following material should be assembled to provide inputs to the decision-making process:

- Wind roses,
- Regional maps of various scales showing topography and developed areas,
- Population data (by town),
- Emissions inventory of point and area sources.
- Diffusion model output (optional).

Climatological wind data in the form of a statistical table such as that shown in Table 4-1, or a wind rose shown in Figure 4-2, are the forms most useful in selecting general-level regional stations. These are examples of some of the kinds of data that are available from the National Climatic Center (NCC) Asheville, North Carolina. The wind rose is particularly useful in depicting the wind direction frequency over the area of interest.

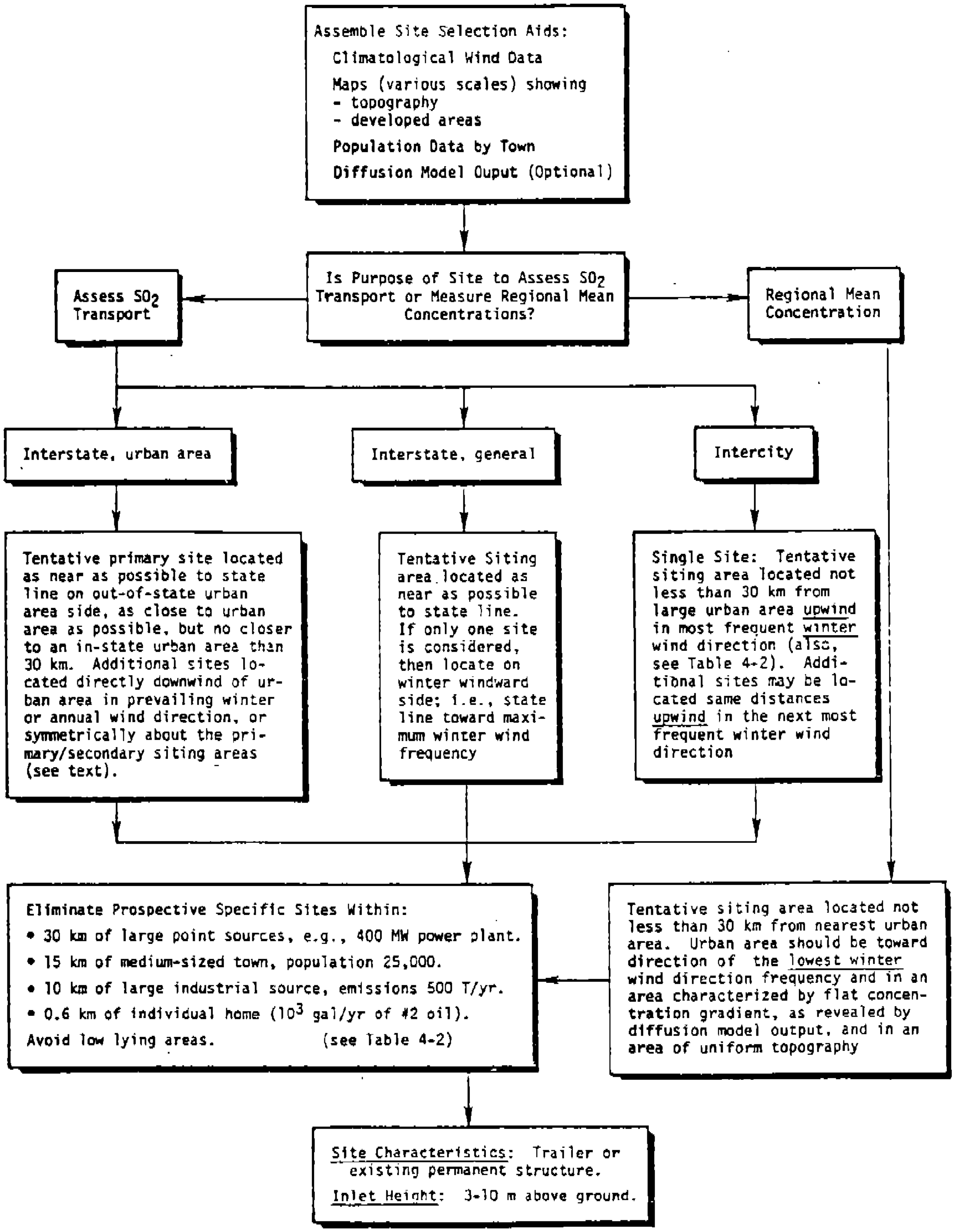

FIGURE 4-1. Flow chart showing procedures for locating general-level regional-scale stations.

TABLE 4-1

Example of a Tabulated Wind Summary
(taken from the National Climatic Center, Asheville, N.C.)

PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED:

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED (IN MILES PER HOUR)										AV SPEED
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	2	1	+	+				4	11.4
NNE	+	1	2	1	+	+				4	10.5
NE	+	1	3	2	+	+				6	11.7
ENE	+	1	2	1	+					4	11.4
E	+	1	1	+	+					3	9.0
ESE	+	1	1	+						2	8.6
SE	+	1	2	1	+	+				4	8.9
SSE	+	1	2	1	+	+				4	11.0
S	1	2	2	3	2	1	+			10	13.3
SSW	+	1	1	3	2	1	+			8	14.4
SW	+	1	1	3	2	1	+	+		8	15.5
WSW	+	1	3	4	4	1	+	+	+	14	17.3
W	+	1	3	5	3	+	+	+		12	15.3
WNW	+	1	2	3	1	+	+			7	14.6
NW	+	1	2	2	1	+				6	13.1
NNW	+	1	1	1	+	+				4	12.0
CALM	+									+	
TOTAL	4	13	30	30	17	5	1	+	+	100	13.5

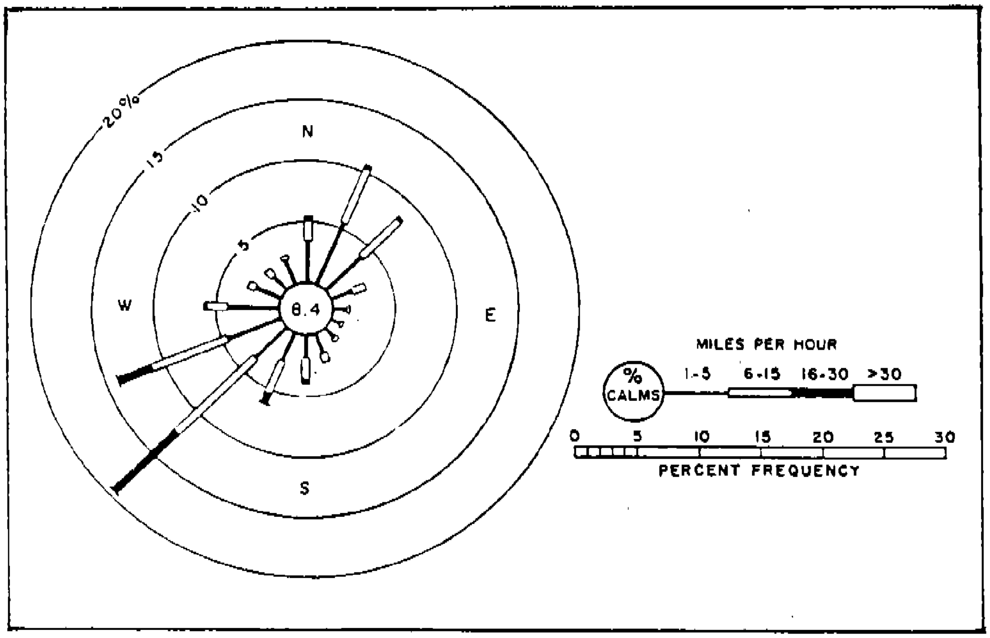

FIGURE 4-2. A typical wind rose with wind-speed information (taken from Slade, 1968).

Maps showing the physical features--natural and man-made--of the region are important since the monitoring purpose and location of the monitors are based on the nature and distribution of these features. Demographic and emission inventory data will provide additional useful inputs.

The selection process begins by deciding on the siting objective after which a specific series of steps is followed. This process is presented below.

4.2.1 Regional Mean (Background) Concentration Stations

A tentative siting area should be established no closer than about 30 km from the jurisdictional boundary of any major urban SO_2 source area in the region. (Consider a city with a population of 2×10^5 or more as constituting a major urban area.) The nearest major urban area should be toward the direction of the lowest winter (Dec, Jan, Feb) wind frequency. If available, a winter seasonal (or annual concentration map generated by a diffusion model can be utilized to ensure that the tentative siting area is not located in an area characterized by a steep concentration gradient ($> \sim 0.5$ $\mu g/m^3$ - km).

The topography of the region containing the urban SO_2 source areas, the tentative siting area, and the NWS station from which the wind rose data originated should be reasonably uniform.

4.2.1.1 Local Characteristics, Interferences and Inlet Placement

Guidelines for considering local physical characteristics, proximity of interfering sources in the vicinity of the final site and instrument inlet placement are the same for all regional scale stations. Once the siting areas have been established, individual prospective sites should be eliminated on the basis of the proximity of small, local SO_2 sources that may unduly influence the measurements. These sources, or source types, and corresponding "interference" distances* are shown in Table 4-2. Regional scale SO_2 monitors should be sited no closer to these sources than the interference distances.

Since low lying areas are associated with relatively higher inversion frequencies, they should be avoided. Open or sparsely forested areas are recommended with the instruments housed in an existing permanent structure or trailer Since all pollutants are well-mixed in the vertical over outlying areas, exact inlet height is not important. A height range of from 3 to 10 m above the ground would be reasonable. In densely forested areas, the inlet tube should be raised a few meters above the tops of the surrounding trees.

Figure 4-3 is a schematic illustrating the tentative siting area for a regional mean concentration station.

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* The interference distances are defined in Section 5.0. They were developed via solutions to the Gaussian point source formula by assuming certain "worst case" conditions.

TABLE 4-2

Source Types and Related Interference Distances for Regional Scale Monitoring Stations

Source Type	Interference Distance
Large point source (e.g., a 400 MW power plant)	30 km
Industrial source (500 tons SO_2 per year)	10 km
Towns (various size population)	
50,000	22 km
25,000	15 km
12,500	10 km
6,000	7 km
Individual home	0.6 km

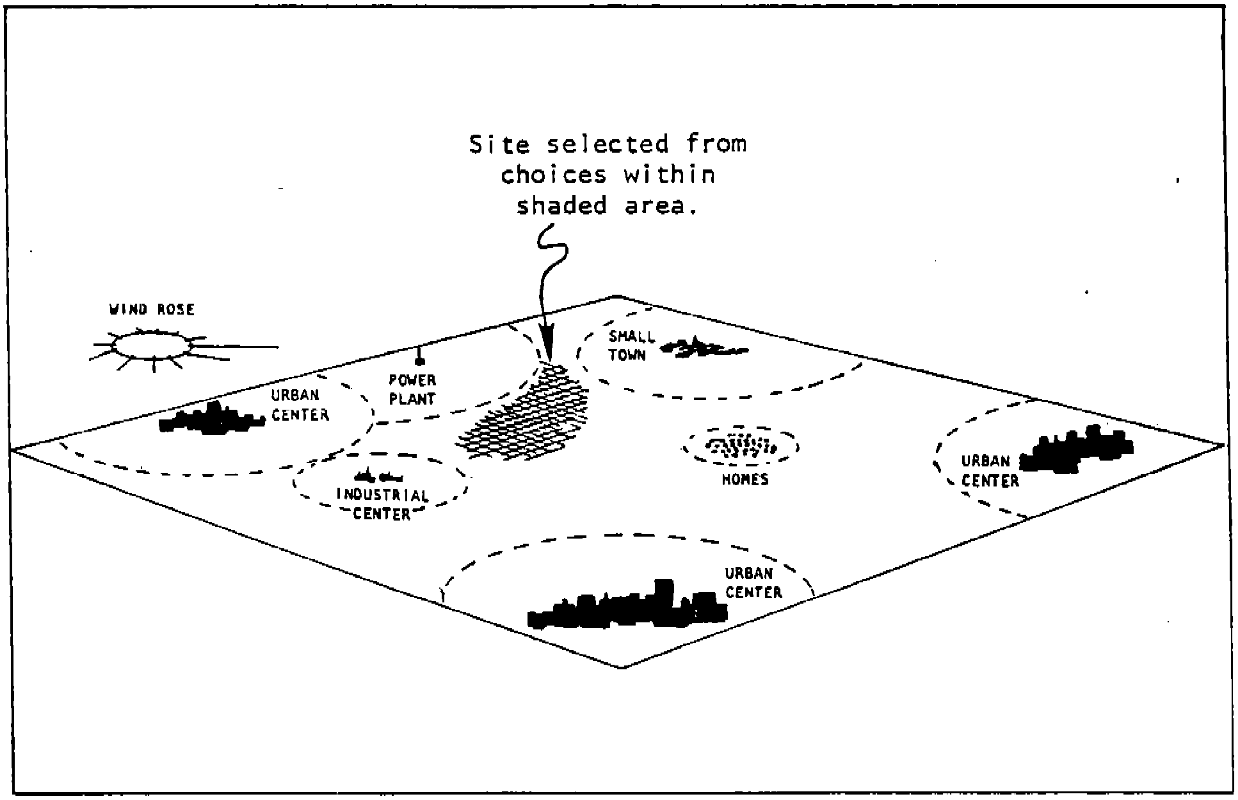

FIGURE 4-3. Schematic illustration showing tentative siting area for regional mean background concentration stations.

4.2.2 SO_2 Transport Stations

SO_2 transport stations may satisfy several siting objectives. Three such objectives and the siting procedures for establishing the stations are discussed below.

- Interstate SO_2 Urban Transport Sites. These sites are established for measuring incoming interstate SO_2 that originates from a large urban complex outside of the state (e.g., New York City/Connecticut; Chicago/Indiana). A primary siting area should be located as close as possible to the state line opposite the out-of-state urban area, but no closer than 30 km to an in-state major urban area. If the state or part of the state is directly downwind of the out-of-state urban area in the winter prevailing direction, a secondary siting area could be established near the state line, as described above, but directly downwind (winter) of the urban area. These are illustrated in Figure 4-4. Alternatively, a series of stations could be placed symmetrically about the primary or secondary siting areas (to obtain horizontal profiles of incoming pollutant, for example).

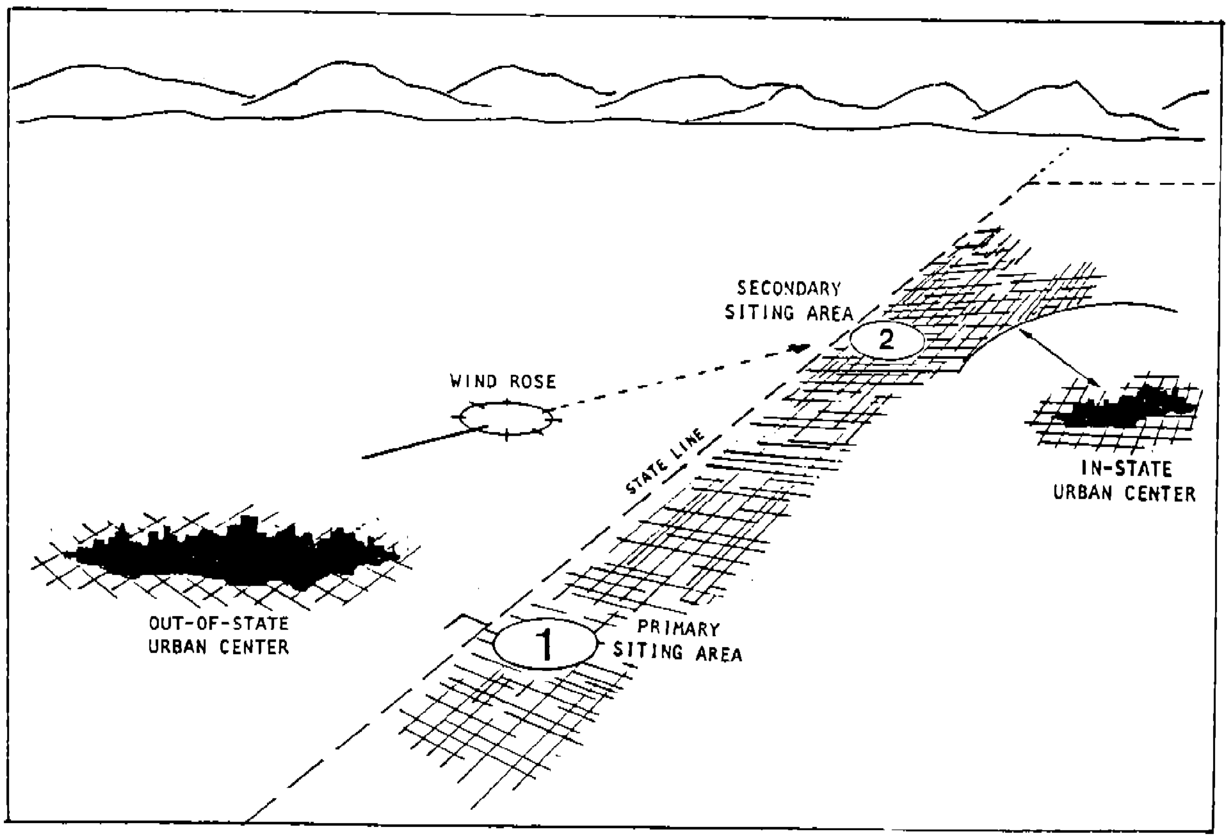

FIGURE 4-4. Schematic illustration showing primary and secondary siting areas for interstate urban transport stations.

- Interstate SO_2 Transport-General. If there are no major out-of-state urban areas contributing significantly to incoming SO_2, a general SO_2 transport station can be established anywhere (but no closer than 30 km to an in-state major urban area) along the winter windward state line.

- Intercity SO_2 Transport Sites. If SO_2 flux entering a city is desired to be measured, a primary siting area may be established upwind of the city boundary in the most frequent winter wind direction, at distances which depend on city size. These distances arange from about 30 km for cities of 2×10^5 population or more to 15 km for small towns of 25,000 population (see also Table 4-2, "Towns"). Secondary siting areas can also be established toward the next most frequent direction, etc. Figure 4-5 shows the location of the siting areas for intercity SO_2 transport stations. Alternatively, other sites may be established directly between two cities, without regard to wind direction, to assess the exchange of SO_2 between the two cities. Similarly, as for the siting areas for regional mean concentration stations, the topography of the entire region should be reasonably uniform.

Guidelines for considering local characteristics, interference distances, and inlet placement are the same as for regional mean concentration stations (see Section 4.2.1.1).

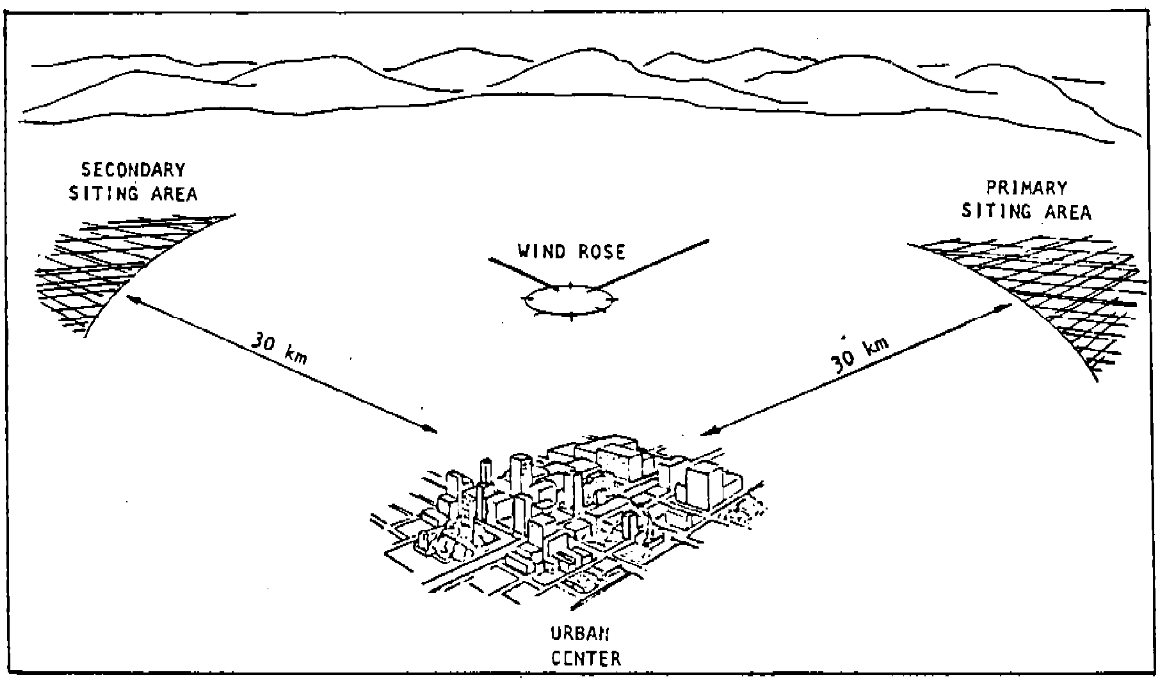

FIGURE 4-5. Schematic illustration showing primary and secondary siting areas for intercity background stations.

4.3 GENERAL-LEVEL, NEIGHBORHOOD-SCALE STATIONS

There are three major siting objectives associated with neighborhood-scale stations--monitoring emergency episodes, determining baseline concentrations in areas of projected growth, and monitoring SO_2 concentrations to which certain human populations are exposed. The specific objectives chosen for which monitoring will be undertaken will determine, in large measure, the siting procedure and kind of background information required.

Figure 4-6 shows the recommended procedure for locating the three kinds of general-level, neighborhood-scale stations. The first step is to decide on the objective of the monitoring, after which follows the gathering of background information and the site selection process itself, as discussed below.

4.3.1 Emergency Episode Stations

The background information required for the proper siting of emergency episode stations includes:

- Emissions inventory of point and area sources,
- USGS map of urban area, and
- Sanborn map of urban area (see Appendix D).

Prospective emergency episode stations should be located near the center of the maximum low-level emission zone(s) of the urban core. The maximum emission zone can be found by plotting the SO_2 emission rates of the area source fraction of the inventory, in tons per year per UTM grid square*, on a gridded USGS map of the urban area. Isopleths of constant emission rate may be drawn as an option to reveal the center(s) of the zone(s). Mobile sampling may also be undertaken during an actual episode or in near-episode conditions (e.g., in the morning when winds are light and variable) to better define the general area of maximum concentration. Figure 4-7 is a schematic illustrating the general location of the prospective siting area.

The final site is selected from a list of candidate sites located near the center of the zone in accordance with the desirable site characteristics and inlet placement criteria as shown in Table 4-3. In general, because very little turbulence and unsteady winds usually prevail during atmospheric stagnations, undue influence from an individual nearby source is minimal. However, if the data from this site is to be used to supplement data from peak concentraion stations, then the site characteristics should be consistent with the criteria shown in Table 4-5 (see Page 45).

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* Emission inventory grid systems normally utilize the kilometer-based Universal Transverse Mercator (UTM) system. UTM tick marks are shown in the margin of most USGS maps.

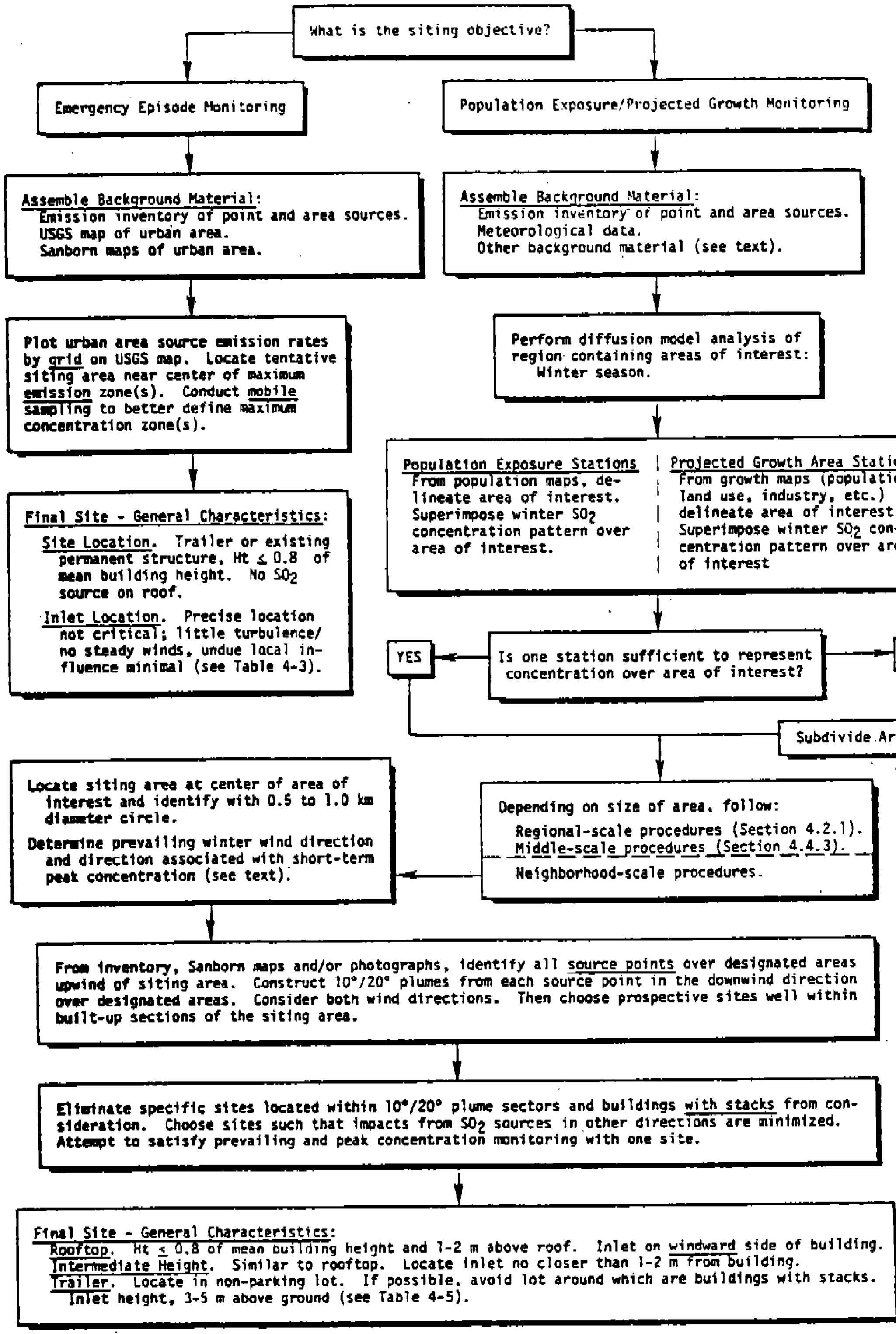

FIGURE 4-6. Flow chart showing procedures for locating general-level neighborhood-scale stations.

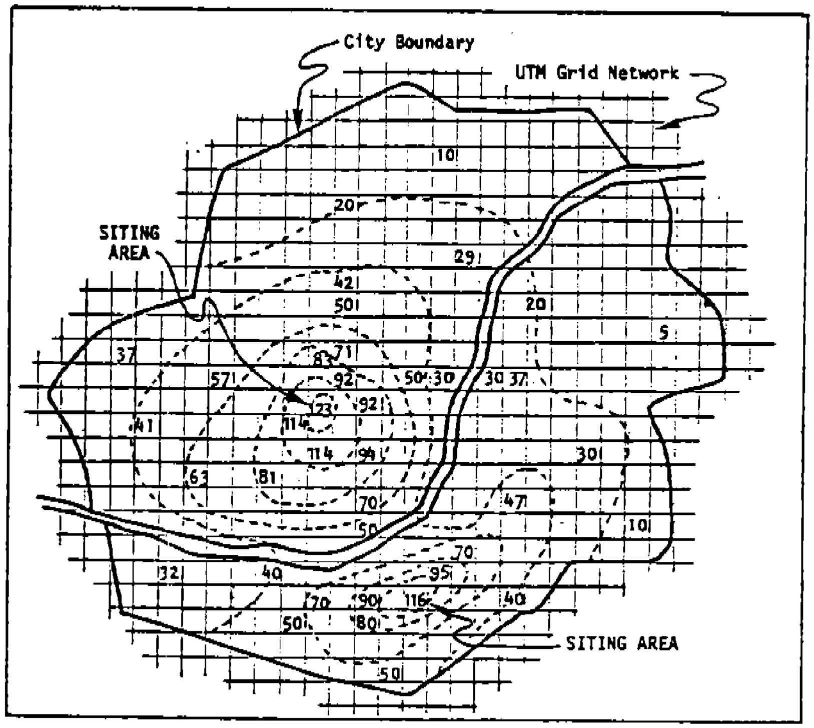

FIGURE 4-7 General location of emergency episode siting area. Numbers indicate relative emission rates. Each grid square equals 1 square kilometer.

TABLE 4-3

Site Characteristics and Inlet Placement Criteria for Emergency Episode Stations

Station Location	Inlet Placement Criteria				
	Height Above Ground	Height Above Roof	Horizontal Clearance Beyond Structure	Horizontal of Inlet Placement	Remarks
Rooftop	Somewhat less than mean height of buildings in zone or lower($\leq -0.8\bar{H}$)*	Not critical. Between 1-2 m, and away from dirty/dusty areas.	Not Applicalbe (NA)	Inlet may be placed anywhere on roof, but away from dirty/dusty areas.	No SO_2 source on roof
Intermediate Height on Building	Same as Rooftop	NA	> 2 meters	Inlet may be located on any side of building, preferable the side away from nearest sources.	No SO_2 source on roof
Trailor	3-5 meters	1-2 meters	NA	NA	If possible, avoid parking lots and other lots around which are buildings with stacks. If located in park, avoid sites under thick "forest" canopy.

* $\bar{H}$ = mean building height in zone.

As a supplementary procedure, population figures could be utilized in a manner similar to that described above for SO_2 emission rates, to determine population densities and characteristics (e.g., age frequencies in the maximum emission zone.

4.3.2 Population Exposure and Projected Growth Monitoring Stations

Siting procedures for these two siting objectives are very much the same after the subject population areas and projected growth (residential, industiral, etc.) areas have been identified and delineated. Since the monitoring of air quality in regions of projected growth is related to the EPA-mandated AQMP process, the reader is referred to Vol. IX of the EPA's *Maintenance Planning Guideline* series of documents (discussed briefly in Section 2.2.7 of this report) for additional information. The siting procedures for projected growth monitoring sites presented below are consistent with the concepts discusses in that document.

The background information and other aids that would be useful for selecting population exposure and projected growth stations include:

- Emission inventory of point and area sources.
- Meteorological data reflecting conditions imposed by topographical and land use setting;* winter season.
- USGS/land use/population mpas of area.
- Air Quality Maintenance Plan (AQMP).
- Sanborn maps of urban area.
- Air Quality Display Model (AQDM) or equivalent.

The emissions inventory and meteorological data will provide the required input to the AQDM for generating an SO_2 concentration field over the areas of interest as well as providing information on the location and strengths of all point sources in the urban area.

After assembling the required background materials, delineate the subject population area and/or the projected growth area, depending on the monitoring objective chosen. Simulate an SO_2 concentration field over the region containing these areas using the AQDM with the emission inventory and meteorology reflecting winter quarter conditions. If the areas of interest are located in large urban areas (population $\geq 10^6$), use a half-life of 1 hour, otherwise use a 3-hour half life. Superimpose the concentration map over the areas of interest. At this point, it must be determined whether measurements from a single site located within the area of interest will represent the entire area of interest. The following general procedure (and illustration shown in Figure 4-8) is recommended for making this determination.

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* Consult diffusion meteorologist to estimate conditions.

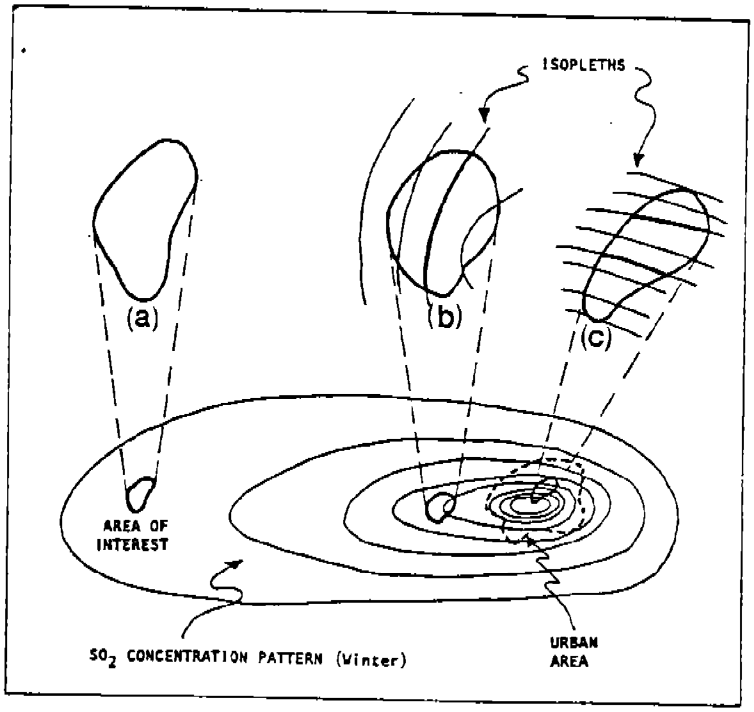

FIGURE 4-8.

Schematic illustrating typical concentration pattern over delineated population or growth areas of interest; (a) area in flat part of gradient, one station probably adequate to represent concentrations over area; (b) probably two sites required; and (c) possibly three sites required: urban setting, representing neighborhood or middle spatial scales.

- If the concentration gradient over the area of interest is no more than about 0.5 $\mu g/m^3$ km, or if the distance between the center of the area and the nearest sources are at least equal to those shown in Table 4-2 (assume monitoring site is near the center of the area), then measurements from a single station located near the center of the area of interest will probably represent the entire area of interest (see Figure 4-8a). Use regional-scale station procedures to determine site characteristics and inlet placement (Section 4.2.1).

- If the extreme concentrations over the area are not within about 25 percent of the mean concentration, then a single site may not be representative of the entire area and more than one station will be necessary to represent the range of concentrations over the area of interest. Divide the area into sub-areas (preferably along an isopleth) until the extreme concentrations over each sub-area are within 25 percent of the mean value (see Figure 4-8b,c). Siting areas should be located near the center of each sub-area. If the sizes of the sub-areas are in the middle scale range (<0.5 km), then middle-scale procedures should be followed (see Section 4.4.3).

The tentative siting area within each sub-area (neighborhood) should be in the vicinity of the mean concentration point of the neighborhood, which is near the center of the neighborhood. Identify the siting area by drawing a circle (0.5 to 1.0 km diameter) near the center of the neighborhood as shown in Figure 4-9. Locate all prospective sites within the siting area and well inside of any built-up area. Eliminate from consideration all buildings with SO_2 source points (stacks). At this point, an elimination process begins, the result of which is the selection of the final site location; Figures 4-9 through 4-11 illustrate the process. The first step is to establish two "upwind" directions (Figure 4-9). One direction is toward the prevailing winter wind direction* and the other is the direction toward the center of the maximum emission zone of the nearest urban area from the tentative siting area. The latter direction represents the most probable direction associated with the maximum short-term concentrations (high background from urban center plus undue local influences). Construct "sector boundaries" upwind of the siting area in both directions as shown. These boundaries enclose the areas containing the most important potential "interfering" SO_2 sources. An arc is then drawn at a distance from each prospective site equal to the "point source interference distance" (PSID).** These distances, for 3 degrees of land use intensity, are shown in Table 4-4 (see Section 5.1 for discussion). Then, from emissions inventory data, Sanborn maps and/or photographs, identify and plot the locations of all SO_2 point sources† within the siting area itself and the area enclosed by the sector boundaries up to the PSID as chosen in Figure 4-10.

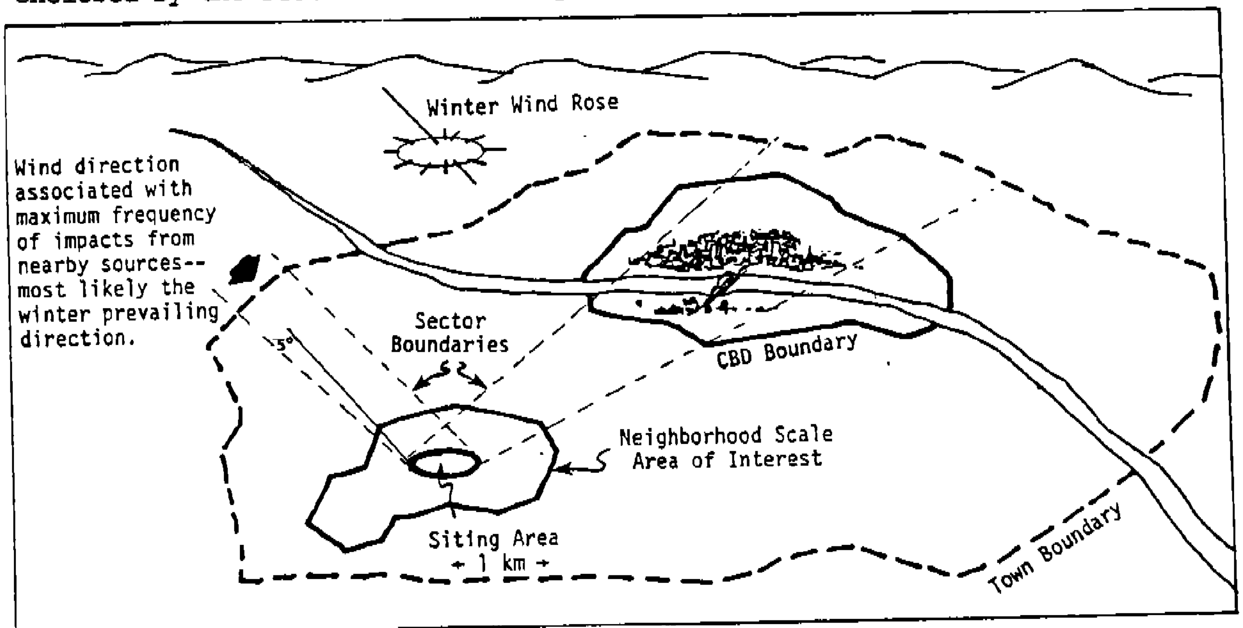

FIGURE 4-9. Schematic illustration of intermediate step by which neighborhood-scale stations are located; identification of siting area, and establishment of sector boundaries within which sources are of concern.

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* This wind direction should be associated with the maximum frequency of occurrence of impacts from nearby sources within the siting area. Directions other than the winter prevailing may be chosen; appraisal by agency may be necessary.

** The point source interference distance (PSID) is the distance beyond which point source impacts are no longer significant at the monitoring site.

† Point sources include all sources identified as such in the emissions inventory.

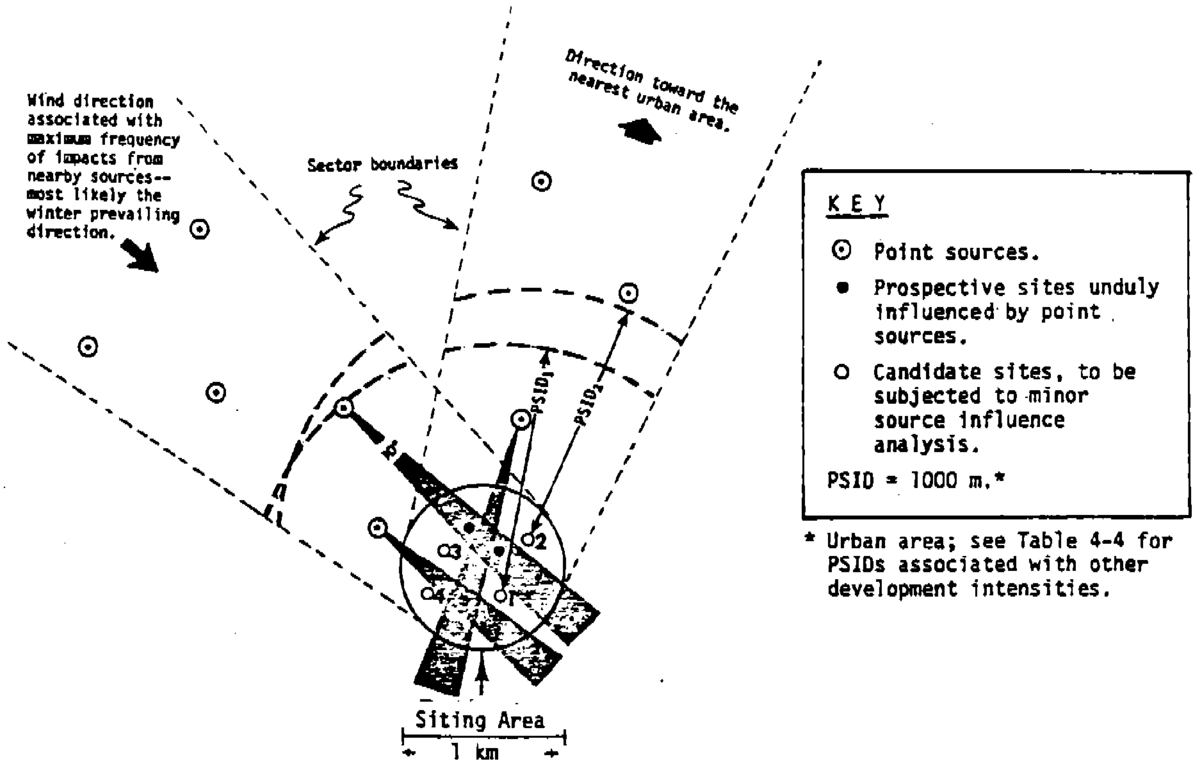

FIGURE 4-10. Plan view blowup of siting area of Fig. 4-9 illustrating the techniques by which final candidate sites are selected.

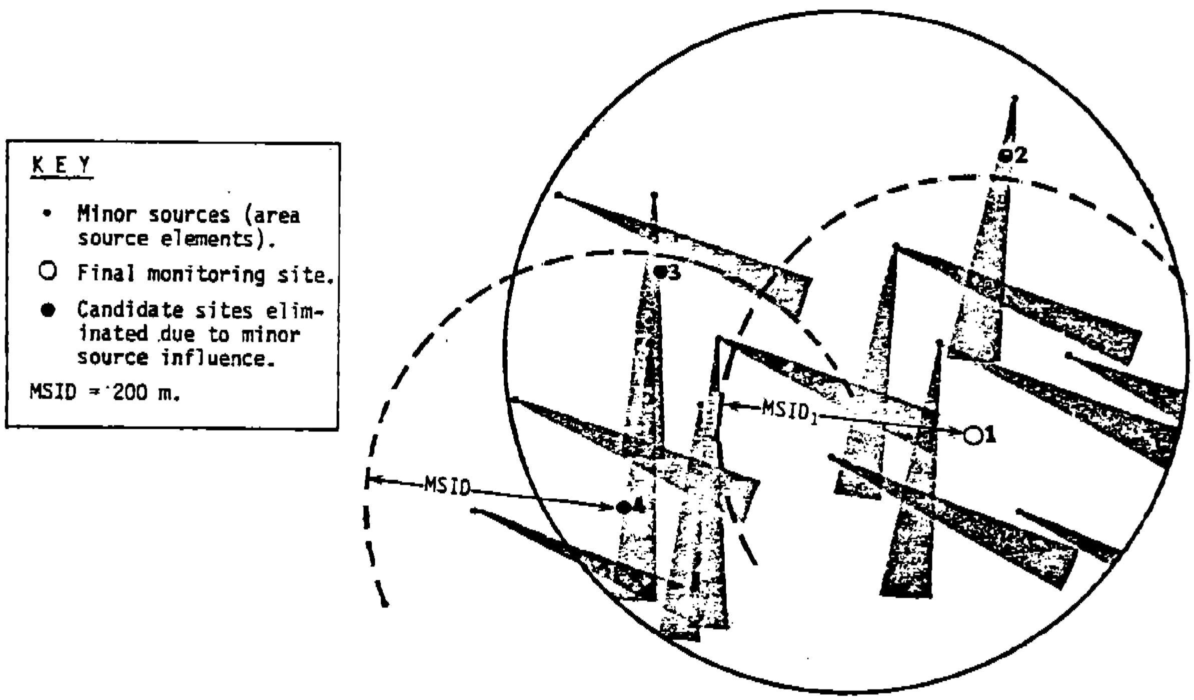

FIGURE 4-11. Blowup of Fig. 4-10 illustrating the technique by which the final site is selected.

TABLE 4-4

Interference Distances for Three Development Intensities*

	Interference Distances	
	Minor Sources (MSID)	Point Sources (PSID)
Urban	200 m	1,000 m
Suburban	100 m	2,200 m
Rural	60 m	3,200 m

The final candidate sites are determined from the following analysis:

- Construct 10° plume sectors downwind of each point source within the PSID of each candidate site.
- Use 20° for the nearest sources (within a city block or two).
- Eliminate prospective sites that fall within any 10° and 20° sector (eliminates undue influences from nearby sources).

The remaining sites represent the set from which the final site will be selected. In a similar manner, identify and plot the locations of all area source elements** within the area enclosed by the sector boundaries up to the minor source interference distance (MSID)† as shown in Figure 4-11. Construct 10° and 20° (nearby sources only) plume sectors downwind of each source and eliminate affected sites. From the remaining sites, select a single site that will satisfy both winter prevailing and short-term peak concentration directions, if possible. Also, the site should be selected such that effects from sources in the other directions from the site are minimal, especially if the wind direction frequency distribution is bi-modal (i.e., high frequencies from two directions, one being the prevailing direction). The procedures used for the prevailing winter direction analysis may be used for this analysis. Figure 4-12 shows the siting area and site locations in better spatial perspective.

If the environment of the siting area is rural in character, the desirable site characteristics and inlet placement are identical to those for regional-scale stations. The desirable site characteristics and inlet placement criteria for sites in suburban and urban environments are shown in Table 4-5.

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* For discussion, see Section 5.1.

** Area source elements are the individual components of an area source such as an individual home or small office building. They can be identified on Sanborn maps or photographs.

† The minor source interference distance (MSID) is the analog of the "PSID" but applicable to the minor sources or individual area source elements.

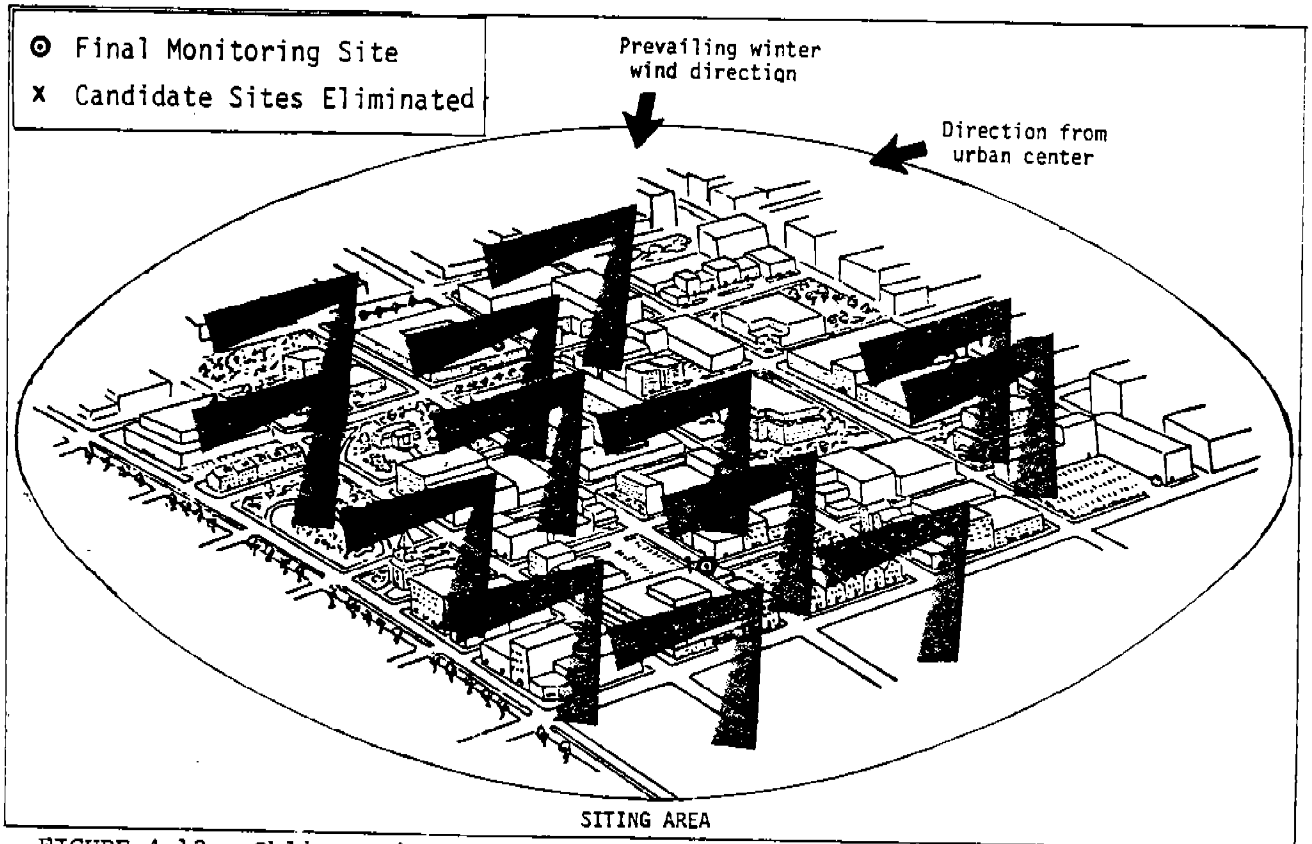

FIGURE 4-12. Oblique view of siting area of Fig. 4-11 showing site locations and urban structure.

TABLE 4-5

Site Characteristics and Inlet Placement Criteria for Neighborhood Stations

Station Location	Inlet Placement Criteria				
	Height Above Ground	Height Above Roof	Horizontal Clearance Beyond Structure	Horizontal of Inlet Placement	Remarks
Rooftop	A little less than the mean height of buildings in neighborhood or lower ($\leq 0.8\bar{H}$*)†	Between 1 - 2 m and away from dirty/dusty areas	Not Applicable (N.A.)	Locate inlet on windward side of building relative to the prevailing winter wind direction, particularly if bluff side of building is toward prevailing direction.	No SO_2 source on roof of building.
Intermediate Height on Building	Same as Rooftop	N.A.	1 to 2 meters	Same as Rooftop	No SO_2 source on roof of building.
Trailer	3 to 5 meters	1 to 2 meters	Not Critical	Not critical	If possible, avoid parking lots and lots around which are buildings with stacks, particularly if nearest building upwind has a large stack. If located in park, avoid sites under thick forest canopy.

* $\bar{H}$ = mean height of buildings in neighborhood (or in middle-scale area of interest for middle-scale stations or in zone of maximum emission densities for emergency episode stations).

† In suburban areas choose a building of low height--preferably one-story.

4.4 GENERAL-LEVEL, MIDDLE-SCALE STATIONS

Middle spatial scales are the smallest practical scales of measurement in routine SO_2 monitoring. Indeed, in an area characterized by a steep SO_2 concentration gradient (in a general-level sense, not an individual plume) measurements made at any one site within the area may represent concentrations on a scale no larger than the middle (see Section 4.3.2).

The major siting objective associated with such scales, in a general-level sense, is to determine peak levels in urban areas. Other siting objectives are the population exposure and projected growth objectives discussed in Section 4.3.2 (normally associated with neighborhood spatial scales) for such areas located in regions of steep concentration gradients.

Figure 4-13 is a schematic illustration of an annual SO_2 concentration profile and associated ground-level pattern that may be observed over an ideally configured city and shows the steep SO_2 gradient that is typically observed. It is within the area of steep gradients that single sites may be located to measure concentrations representing middle-spatial scales. Also shown in Figure 4-13 are example relative locations of stations sited for the above objectives. Actually, most cities are irregularly configured or have industrial complexes and power plants off to one side resulting in irregular SO_2 concentration patterns; nevertheless, the above representation is still relevant.

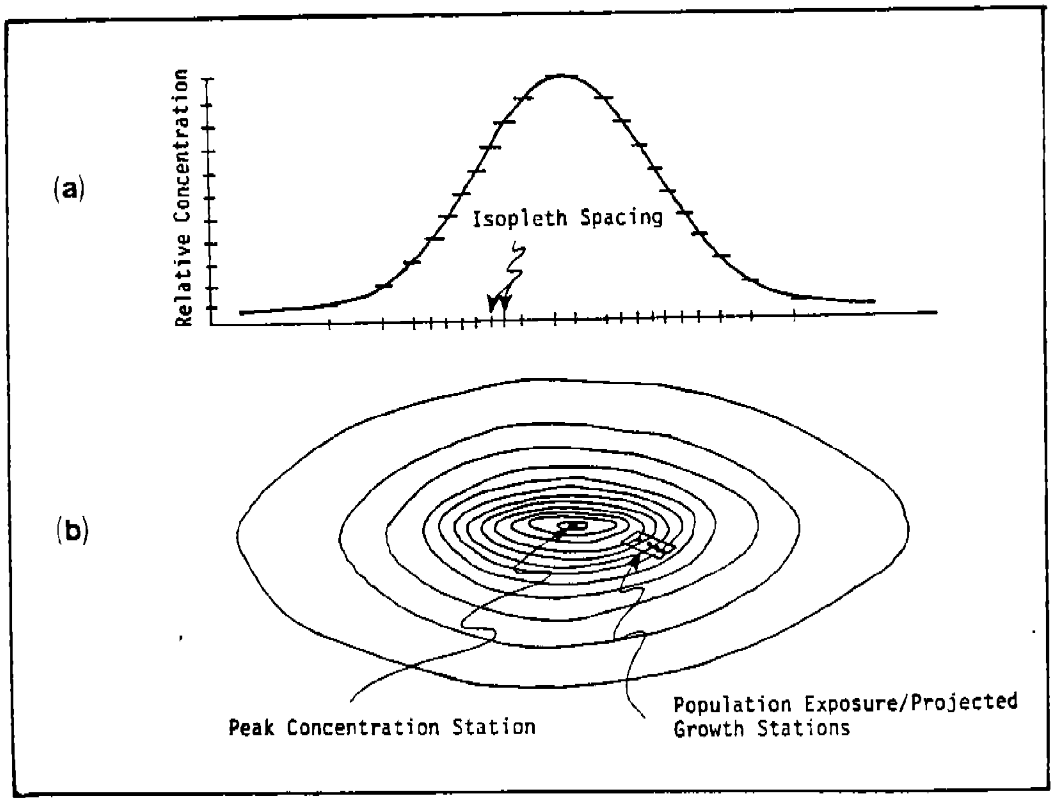

FIGURE 4-13. Schematic illustration of (a) idealized SO_2 concentration profile; and (b) its associated ground-level pattern and example site locations.

Peak concentration stations are "pattern oriented"; i.e., the location of the peak concentration point of the concentration field determines where the site is established. Diffusion modeling plays the primary role in making this determination. The population and growth sites, on the other hand, are associated with fixed geographical areas and are located within these fixed areas regardless of the features or characteristics of the SO_2 pattern over the areas. The procedures for siting these two kinds of monitoring stations are discussed separately below.

Figure 4-14 is a flow chart showing the recommended procedure for selecting general-level middle-scale stations. If the objective of the monitoring is to assess population exposures to SO_2, or areas of projected growth (neighborhood-scale procedure having been deemed inappropriate, Section 4.3.2) the final steps for determining these sites are discussed later in this section. Otherwise, the first step is to assemble the required background material related to the selection of sites to establish peak concentration stations:

- Emissions inventory of point and area sources.
- Meteorological data (see Appendix A)
- USGS map of area.
- Sanborn maps.
- AQDM or equivalent model.

4.4.1 Peak Concentration Stations

Perform an SO_2 simulation analysis of the urban area using the AQDM (or equivalent model) with meteorological data and point and area source emission rates reflecting winter conditions (Dec, Jan, Feb).* For large urban areas (population $\geq 10^6$), use an SO_2 half-life of one hour. For other urban areas, use a three-hour half life. Generate the winter mean, 24-hour "worst case" and three-hour "worst case" SO_2 concentration patterns over the area. An approach for generating such short-term worst case patterns is suggested in Appendix B. In any case, a diffusion meteorologist should be consulted.

4.4.1.1 Winter or Annual Peak Concentration Station

Identify the location of the maximum concentration point on a USGS or detailed city map. (This can be accomplished quite easily if one-kilometer model output grid spacing and isopleth analysis is used.) Then, draw a 500-meter

* If the location of the annual concentration peak would be better estimated by averaging four seasonal simulations rather than the winter pattern alone, then this should be done; for example, in cities where there are power plants, many of which emit peak or near-peak SO_2 rates in summer. For cities having less than about 1500-2500 heating degree days per year, a single annual simulation should suffice, unless industrial sources and/or power plants exhibit seasonal emission patterns.

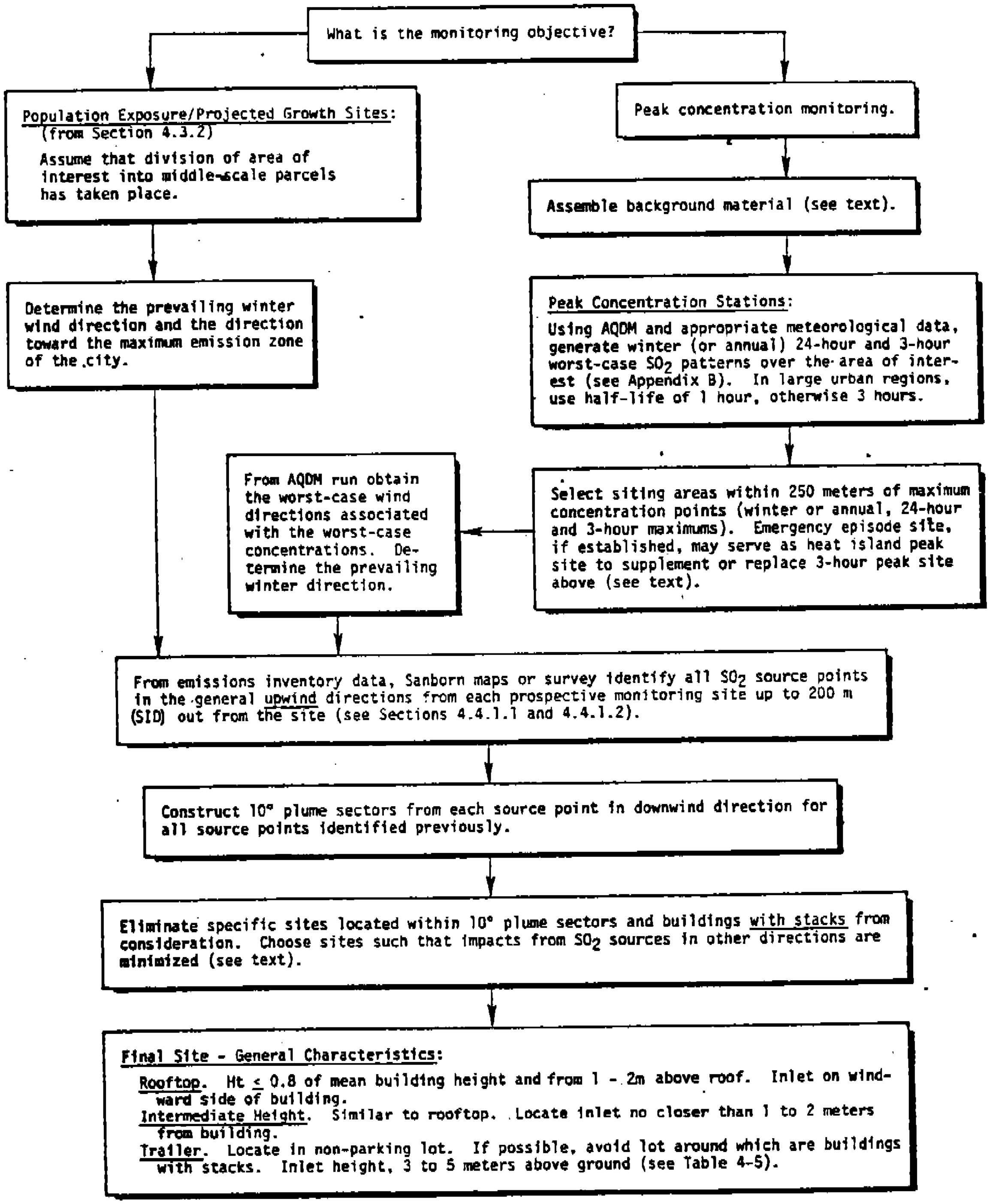

FIGURE 4-14. Flow chart showing procedures for locating general-level middle-scale stations.

diameter circle centered on that point. This circular area represents the upper limit of the middle spatial scale and defines the most probable area within which the maximum winter (and annual) peak concentrations occur.

Locate all prospective monitoring sites within the circular area. Eliminate from consideration all buildings with SO_2 source points (stacks). Next, using a procedure similar to that described for neighborhood stations, establish the prevailing winter (or annual, whichever applies) upwind direction and draw arcs 200 meters from each prospective monitoring site in the upwind direction. This 200-meter distance is the "source interference distance" (SID).* See Figure 4-15 for an illustration of the procedure.

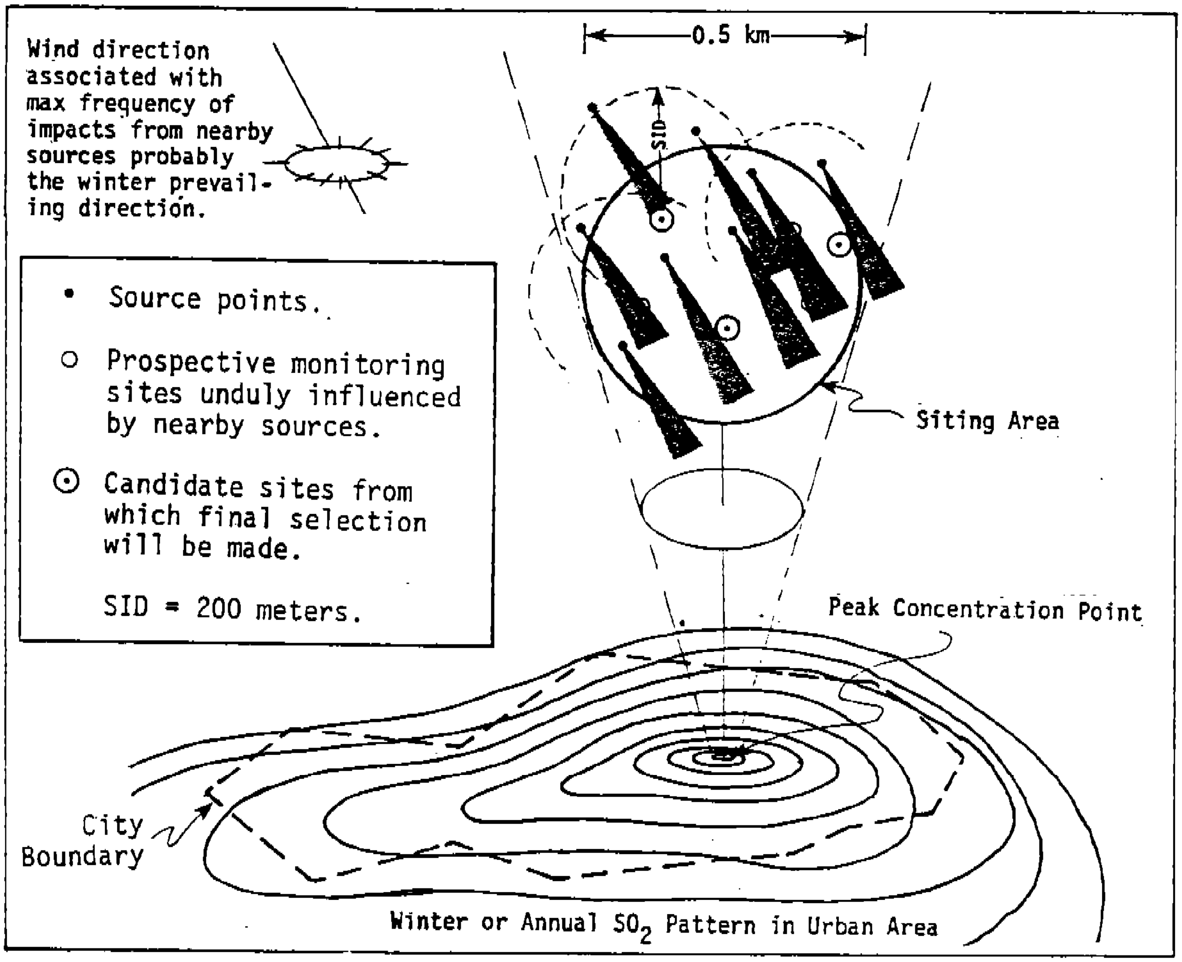

FIGURE 4-15. Schematic illustration of middle-scale siting procedure for peak concentration stations.

* Since we want to measure the maximum collective annual impacts from all point sources, the SID applies only to area source elements. In that sense, the SID is analogous to the PSID.

From the emissions inventory, Sanborn maps and/or survey results identify and plot all SO_2 source points (stacks) within the siting area and up to the SID in the upwind direction. Draw 10° plumes downwind from all source points located within the SID of each prospective monitoring site as shown. The final site is selected from among those sites not intersected by a 10° plume. Since we are now dealing with spatial scales in which we are becoming interested in impacts from local sources, the use of 20° sectors is not so important and their use is optional.

The above analysis should be extended to other wind directions proceeding from the next most frequent until only one prospective site location remains. This will be the final site location and could be considered permanent. The physical characteristics of the site and inlet exposure are the same as those shown in Table 4-5 (see Page 45).

4.4.1.2 24-Hour and 3-Hour Maximum Concentration Stations

The procedure for locating these stations are the same as for the annual peak station except for the following points.

1) Assume that the short-term peaks occur in winter. Their locations will be determined on the basis of winter simulation analyses.*

2) The wind directions used will be those of the worst case meteorology--i.e., those which are associated with the 24-hour and 3-hour concentration peaks.

3) Regarding the peak 3-hour station, prospective stations should be considered temporary with the final site location refined on the basis of mobile sampling. Such sampling should be done when the 3-hour worst case meteorological conditions are forecast.

4) There is an alternative to the 3-hour site location as determined from the above analysis. It is possible that the 3-hour peak concentration occurs under an inversion situation with a general inflow of air toward the urban center ("heat island" effect). The urban center here can be considered the area of the maximum SO_2 emission density due to area and point sources, analogous to that associated with the emergency episode stations. It is not unlikely that the maximum temperature excess point, air inflow convergence point, and peak concentration point will be found near the center of this area. Thus, unless the addition of point sources to maximum emission zone calculations significantly changes the location of the zone based on area sources alone, or if the city is geographically complex, the emergency episode station(s) can be considered a heat-island related 3-hour peak station as well.

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* If only major point sources contribute significantly to urban SO_2, see Section 4.5.

It is possible that some or all of the peak concentrations (3-hour, 24-hour, and annual) occur near the same location. In these cases, only one site will be required and located/verified by using the procedures applicable to each averaging time involved.

If there is a choice between the 3-hour peak site based on diffusion model results versus the emergency episode station, consider both but make the final decision on the basis of mobile sampling (as addressed in Item 3 above) results. See Table 4-5 (Page 45) for site characteristics and inlet exposure criteria.

4.4.2 Population Exposure and Projected Growth Stations

The siting procedures for these stations are a continuation of the procedure described in Section 4.3.2 (second item of decision process for determining number of sites required for characterizing area of interest) and by Figure 4-8c (see Page 41). Therefore, at this point it can be assumed that the area of interest has already been divided into an appropriate number of middle scale parcels. The siting procedure continues by first establishing a siting area in each parcel. Try to limit the siting area to the central strip of the parcel as shown in Figure 4-16. Then, use the annual peak station siting procedure discussed in Section 4.4.1.1, but with one additional wind direction--that defined by the direction of the siting area and the center of the maximum emission zone of the city (for example, see Figure 4-9, Page 42). This wind direction defines the most probable direction associated with the shorter term peak concentrations resulting from center city sources, which almost certainly impact essentially uniformly over the entire parcel.

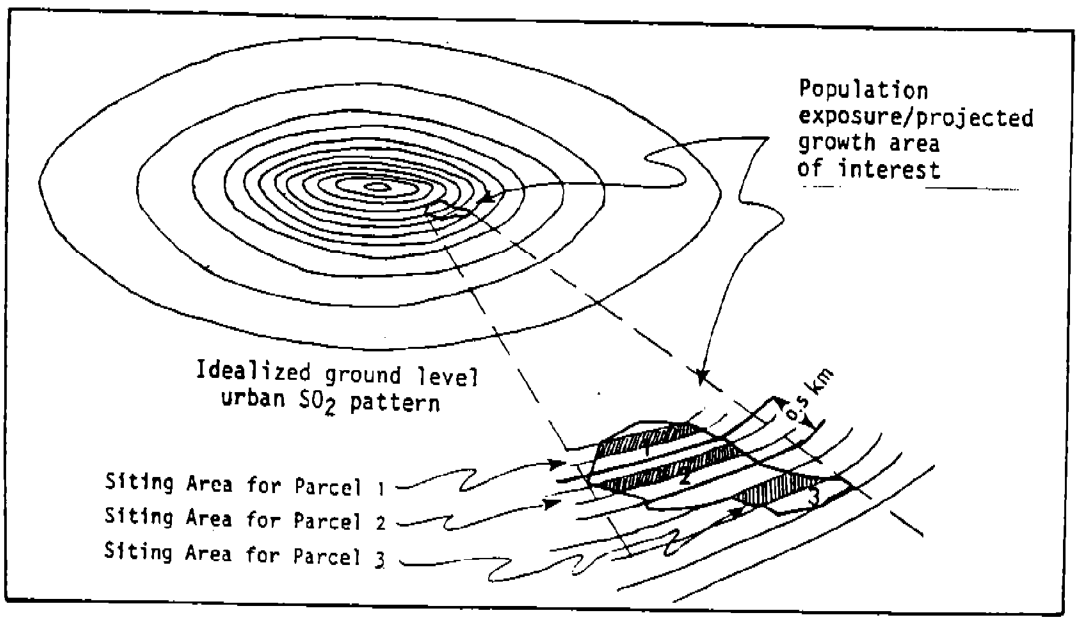

FIGURE 4-16. Schematic showing population exposure or projected growth area divided into middle-scale parcels and recommended siting areas.

The final site should be chosen such that nearby local sources in this direction also will not unduly impact at the monitoring site.

4.5 PROXIMATE, MIDDLE-SCALE STATIONS - Urban Sources

There are two siting objectives associated with proximate, middle-scale stations--assessing the impact of a major point source in a multi-source urban setting, and assessing the impact of an isolated point source. The procedures for siting monitors to satisfy the first objective are heavily dependent on the results of multi-source diffusion model simulations, point source diffusion calculations and "χ/Q" type analyses. For the second objective, knowledge of plume behavior in various terrain environments, special surveys, and mobile sampling results may also be required. Although middle-scale measurements are associated with both objectives, the selection procedures for siting monitors to achieve the two objectives are totally different. In this section, only the first objective is addressed. Isolated point source monitoring is discussed in Section 4.6.

Figure 4-17 is a schematic illustrating the concept of the impact of a major point source in an urban setting. In this situation, the specific siting objectives are to:

- measure the impact of the point source at the urban peak concentration point (Figure 4-17a, point χ), and
- measure the maximum impact of the point source itself (at point P of Figure 4-17a,b).

Averaging times of 3 hours, 24 hours, and one year should be considered, particularly the shorter averaging times.

Figure 4-18 is a flow chart showing the procedure for locating middle-scale stations for assessing the impact of individual urban point sources. The first step is to assemble all background information. This will include:

- Physical data from point source
  - peak and daily mean production rate of SO_2
  - stack parameters
  - exact plant location.
- Emission inventory of point and area sources.
- Meteorological data
  - stability wind roses (see Appendix A)
  - wind persistance tables (see Appendix B, Part I).
- USGS/Sanborn maps of urban area.
- Frequency statistics of hourly wind speed and direction (annual data).

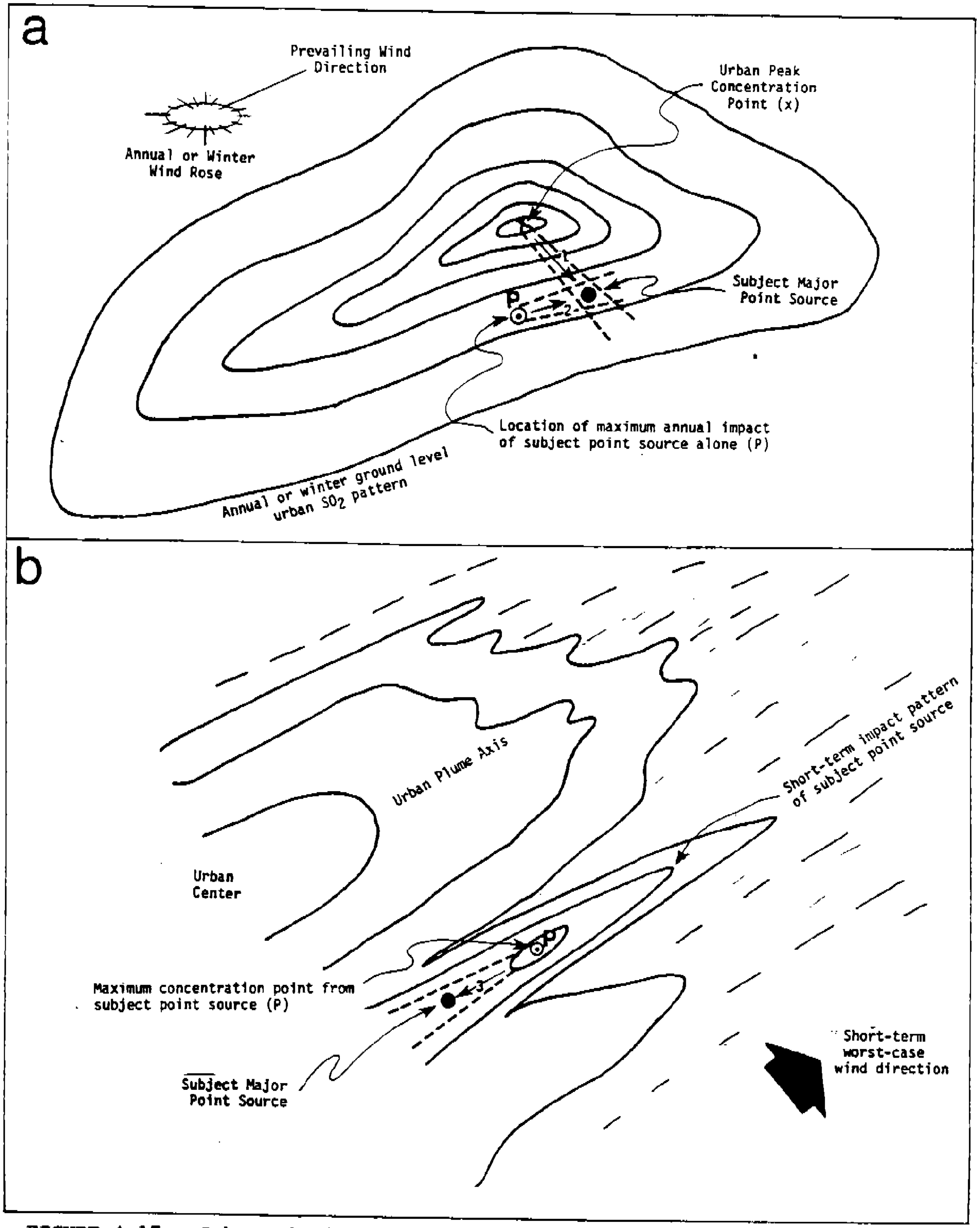

FIGURE 4-17. Schematic illustration of impact of point source in an urban setting for two averaging times: (a) annual pattern, and (b) short-term pattern.

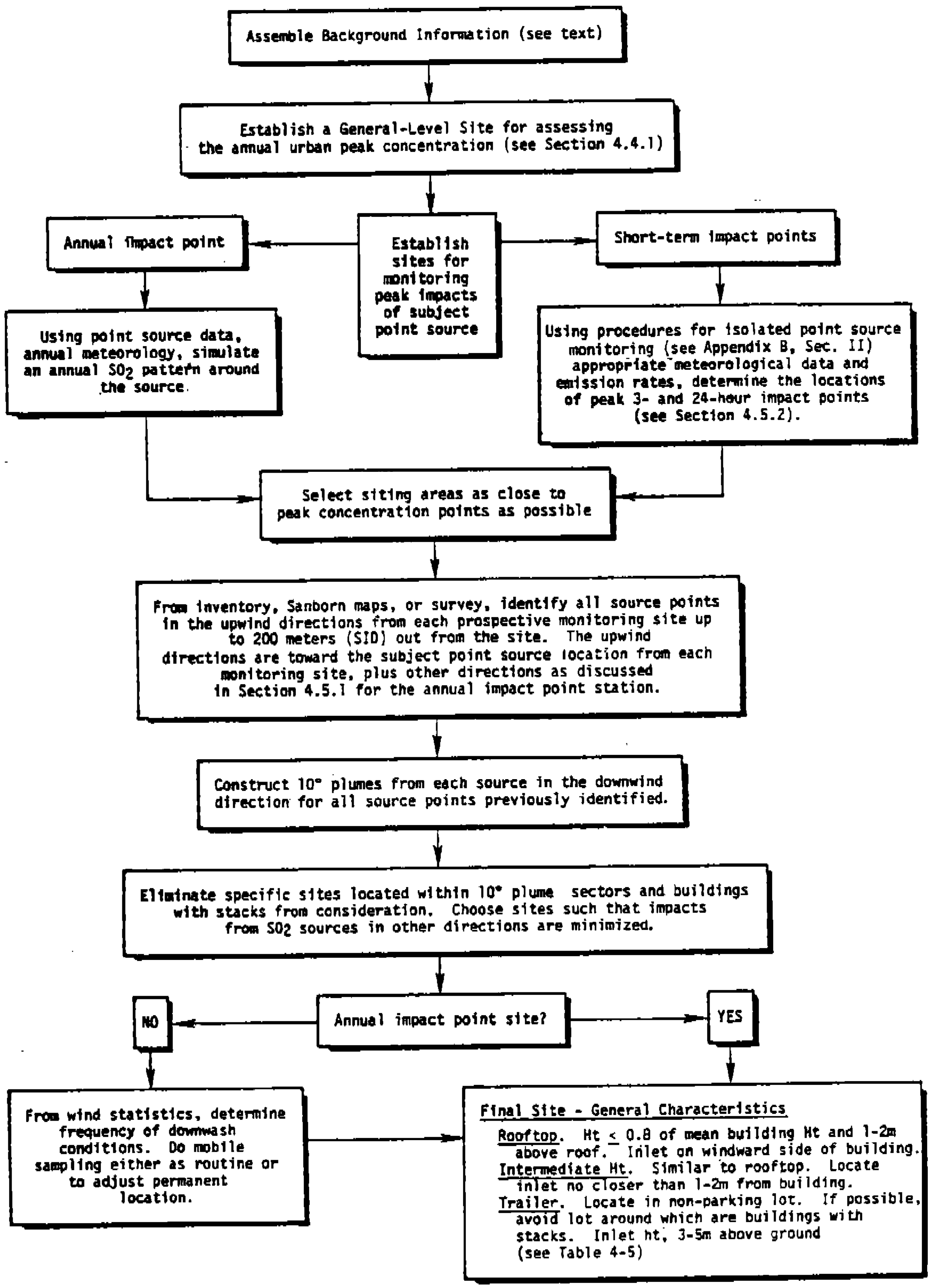

FIGURE 4-18. Flow chart showing procedures for locating proximate middle-scale stations.

4.5.1 Annual Peak Concentration Stations

4.5.1.1 General-Level Urban Peak Station

If a monitoring site has not already been established to monitor the general-level (urban) peak annual concentration, establish such a site (point X in Fig. 4-17a) by using the procedures presented in Section 4.4.1.1 for the annual peak stations. However, in the procedure for dealing with undue local impacts (illustrated in Fig. 4-15) consider the direction *toward the subject point source* from the siting area (direction "1", Fig. 4-17a) as well as the winter (or annual) prevailing direction.

4.5.1.2 Proximate Station

The remaining steps of this procedure pertain to the siting of an additional monitor to assess the maximum annual impact from the point source itself. Using the AQDM with annual* meteorological data, appropriate half-life value, annual* average emission rate and stack characteristics of the point source only, simulate the annual* SO_2 pattern around the source and establish a siting area centered on the maximum concentration point, Point "P" in Figure 4-19 (which is point "P" in Fig. 4-17a). Figure 4-19 shows the annual SO_2 pattern due to the point source only. The next few steps are the same as those discussed in Section 4.4.1 (illustrated in Fig. 4-15 in that section), except that an additional direction must be considered for identifying another critical sector that contains sources which may produce undue influences--*the upwind direction between the siting area and the subject point source* (direction "2", Fig. 4-17a); however, this direction is probably the same as the prevailing wind direction for the time period simulated. Use Table 4-5 for final site characteristics and inlet exposure.

4.5.2 24-Hour and 3-Hour Maximum Concentration Stations

These stations are analogous to the 24-hour and 3-hour maximum concentration stations associated with the urban peaks except that these assess the peaks due to the subject point source alone (Point "P" in Fig. 4-17b). In this case, we can pretend that the point source is located in an <u>isolated</u> area of rough topography. The location of the peak 24-hour and 3-hour average concentration points due to the source, and associated "worst case" meteorology can be determined by an approach suggested in Appendix B, Section II. After determining these locations, use the procedure found in Section 4.4.1.1 (regarding annual peak stations) for selecting the siting area and specific station locations. However, in this situation, only one wind direction is used for determining undue influence of nearby sources--the direction from the siting area toward the subject point source (direction "3", Fig. 4-17b).

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* If the emission rates and meteorology vary significantly over the year, it may be better to use the average of four seasonal simulations; if subject point source emissions are degree-day dependent, use winter meteorology.

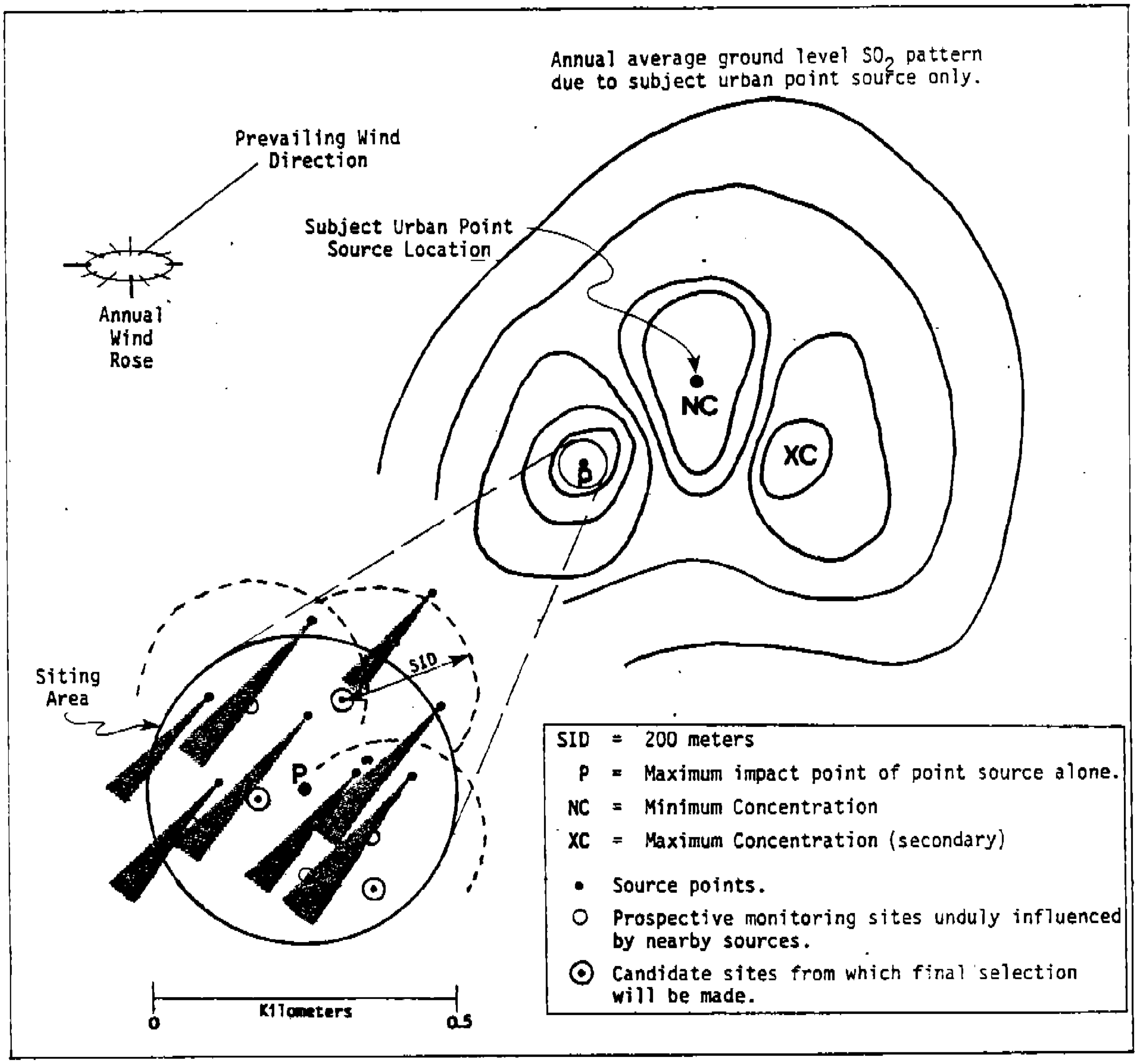

FIGURE 4-19. Schematic illustration showing annual impact pattern due to urban point source alone, the siting area, and final candidate sites for assessing the annual impact from the point source.

Before deciding on a final site location, it might be a good idea to determine the expected frequency of downwash conditions. (It is recognized that over large urban areas in the daytime, downwash conditions are the rule rather than the exception, especially for the lower level sources. However, for the larger (and more elevated) sources such may not be the case; but, because the sources are large, if and when downwash occurs the ground-level impact of such occurrences could be substantial.) If the wind statistics (e.g., see Table 4-6) for the area show that the stack exit velocities are less than 1.5 times the wind speed (Sherlock and Stalker, 1941), or if the height of the stack is not at least 2.5 times the height of the highest surrounding buildings (Hawkins and Nonhebel, 1955), downwash conditions are likely. Sanborn maps or surveys will resolve the latter situation. To resolve the former, the following procedure is recommended:

> From load curve and/or hourly fuel consumption data obtained from the source, determine the typical hourly exhaust gas flow and velocity rates. Then tabulate these velocities by the hour and compare them to the hourly wind speed frequencies of Table 4-6 for the same hour. If downwash conditions will be frequent, mobile sampling may be necessary, either as a routine operation to monitor the 3-hour peak or to determine the location of a final permanent site, or, perhaps, even to delineate a new siting area within which a permanent site will be selected. Use Table 4-5 (see Page 45) for final site characteristics and inlet exposure.

TABLE 4-6

Percentage Frequencies of Sky Cover, Wind, and Relative Humidity (Taken from NCC)

HOUR OF DAY	CLOUDS SCALE 0-10			WIND SPEED (M.P.H.)				RELATIVE HUMIDITY (%)					
	0-3	4-7	8-10	0-3	4-12	13-24	25 & OVER	0-29	30-49	50-69	70-79	80-89	90-100
00	18	8	75	4	46	46	5		4	17	30	32	20
01	17	7	75	4	46	44	4		1	18	27	35	19
02	15	6	79	5	45	45	5		1	16	29	34	20
03	17	5	78	5	45	44	5		1	18	30	33	20
04	15	7	77	4	48	43	5		1	15	28	34	22
05	15	9	76	4	47	42	7		1	16	28	34	21
06	14	7	79	5	48	41	6		1	15	32	32	20
07	10	11	78	5	47	42	6			15	34	32	20
08	10	8	82	4	48	43	5		1	14	33	34	18
09	12	10	78	5	44	44	7		1	20	34	28	16
10	12	12	76	4	38	52	6		2	29	28	27	14
11	11	14	75	2	40	52	6		3	35	25	22	15
12	10	14	77	2	35	54	9		3	34	28	18	15
13	10	13	77	5	31	54	11		3	40	25	16	15
14	9	15	76	4	35	55	7		5	42	22	16	15
15	10	14	76	3	35	55	8		5	40	22	18	15
16	11	15	74	2	41	52	5		6	37	25	18	16
17	14	15	71	3	47	45	5		2	31	30	21	16
18	15	13	72	5	45	46	4		2	27	29	27	16
19	18	9	73	5	43	48	5		1	24	29	29	17
20	16	11	73	4	42	50	5		2	21	31	28	19
21	18	11	71	4	43	50	4		1	21	31	30	18
22	18	9	73	4	44	47	5		4	18	35	29	18
23	20	8	72	5	44	45	6		1	16	31	32	19
AVG	14	10	76	4	43	48	6		2	24	29	27	18

4.5.3 Data Interpretation

The total concentration of SO_2 in the samples taken at the above sites consists of contributions from most of the sources in the urban area as well as that from the subject point source. The former may be considered as background noise that cannot be separated from the total. Therefore, to estimate the percentage of the sampled concentration due to the subject point source alone, diffusion modeling must be utilized. Figure 4-20 illustrates the recommended approach very well for the annual situations. The two vertical profiles on the right side of the figure are source contribution results computed by the AQDM model at the indicated points of interest. Displayed as seen in the figure, they may be interpreted as "source contribution profiles" and represent the best estimate of what each source contributes to the total concentration at those points. In this case, there are two points of interest--the urban annual peak concentration point, and the corresponding impact point "P" (pattern, lower left corner), where the maximum annual impact from the point source of interest ("10") occurs. The upper profile represents the highest total concentration in the entire urban area, and in this particular case, source 10 contributes the least to that concentration. (However, it is more than likely that in the real world any point source worthy of individual attention will almost certainly contribute substantially to the highest urban peaks.) The lower profile represents the total concentration at source 10's maximum impact point, with source 10 being the largest contributor to that concentration.

In a similar approach, for the short-term impacts, the 3-hour and 24-hour worst case meteorology, and emission data (appropriate for season in which the worst cases occur) for the entire urban area can be input to the AQDM to determine the short-term background concentrations at the maximum impact points of the subject point source. Source contribution profiles may also be generated by the model and analyzed in a manner similar to that discussed above.

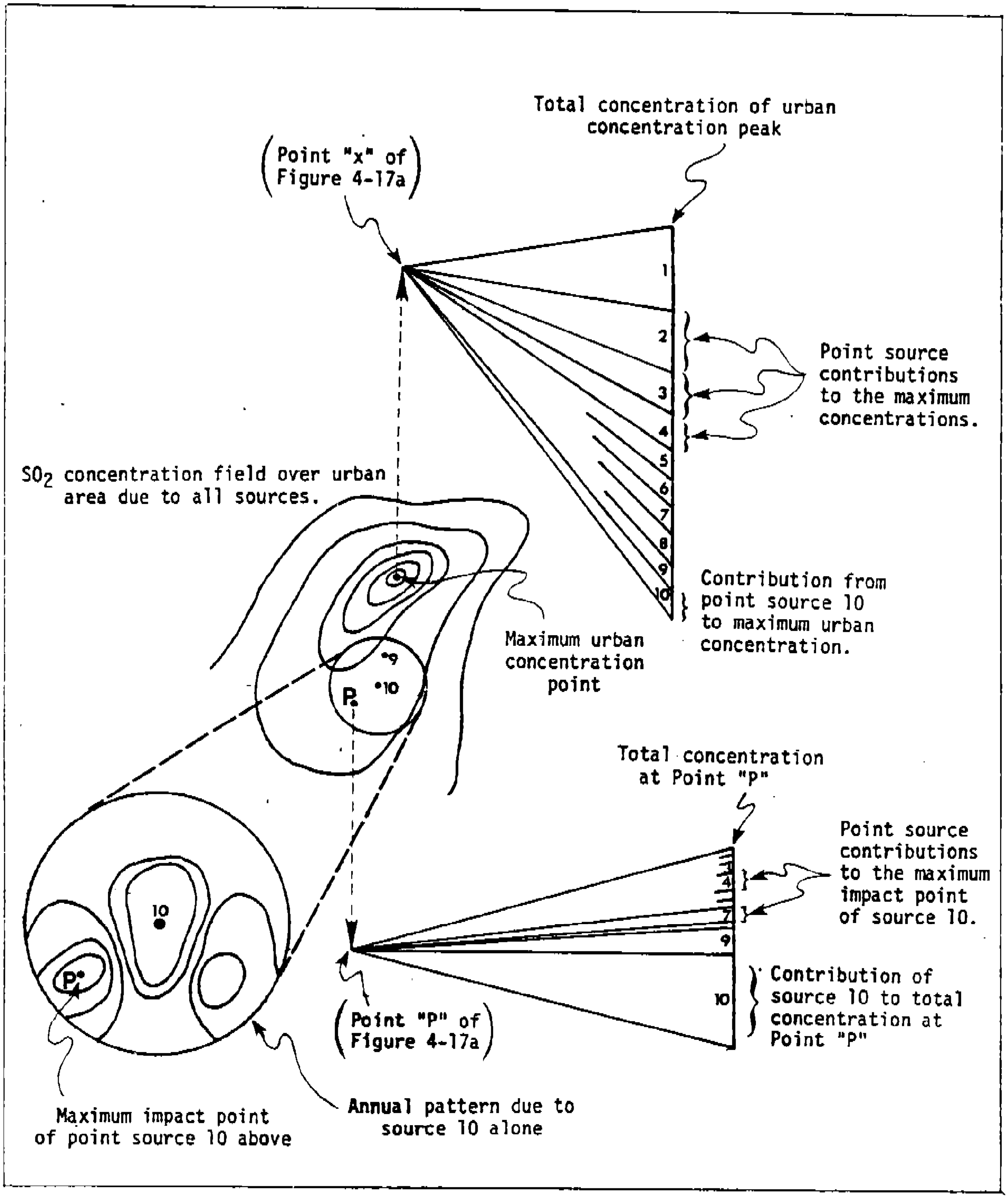

FIGURE 4-20. Schematic illustration of the concept of the source contribution profile in an urban area for the annual pattern (a synthesis of Figures 4-17a and 4-19).

These kinds of analyses should be performed at each monitoring site to estimate the percentage of the measured concentration due to the point source of interest. The model used can be run either calibrated or uncalibrated, but appropriate half-life decay factors should be used. A yearly analysis with updated meteorological and emissions data is recommended in order to explain trends and to determine relative effects of control strategies.

4.6 PROXIMATE, MIDDLE-SCALE STATIONS - Isolated Sources

Because of the great variety of physical environments in which isolated point sources* are found, it was not possible to develop a single set of procedures for selecting sites for monitoring the impacts of such sources applicable uniformly, in all environments. Therefore, where possible, it was decided to present examples of monitoring site configurations, each reflecting an approach to the site selection problem in a given characteristic physical environment. In other situations where typical settings can be extremely varied and complex, only a general description of the kinds of siting problems expected to be encountered in such settings is discussed, mainly in terms of "points to consider". It is hoped that these examples will serve as guides for the site selector in developing the steps necessary for the proper siting of monitors in specific situations. In presenting the examples, specific points will be addressed wherever possible to help the site selector in developing and executing the steps.

The material presented is essentially an expansion of existing guidelines (EPA,1974b) but with more emphasis placed on the use of the diffusion equation and graphical aides in selecting monitoring sites. Additional points addressed include problems of plume behavior in various terrain environments and the role of mobile sampling in the site selection process. In this regard, in some situations it may be necessary to determine the distribution of the plume material in order to ascertain the plume's statistical characteristics; this will require microscale measurements, most easily accomplished via mobile sampling. For a rather comprehensive overview of isolated point source monitoring, the reader is referred to a paper by Paulus and Rossano (1973).

The situations described in this section will also be applicable to monitoring networks established to satisfy supplementary control system (SCS) requirements. Since these systems are rather complex and comprehensive (i.e., they integrate ambient and in-stack monitoring, diffusion modeling, emission controls, etc. in a predictive scheme) detailed treatment of the subject was considered beyond the scope of this report. However, a description of the components of a typical supplementary control system can be found in the Federal Register, Vol. 38, No. 178, Friday, September 14, 1973. See also Montgomery, et al. (1975) for a description of TVA's SCS system.

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* Point sources in this context consist of power plants, sulfide smelters, sulfuric acid plants, coal conversion plants, or refineries located away from populated or developed areas.

The material presented below includes typical examples of isolated point source monitoring problems expected to be encountered in a variety of physical terrain settings. The major role expected to be played by mobile sampling would be either in routine monitoring or in the refining of preliminary site locations for permanent monitoring stations. (To maintain the continuity of the section, the concept of mobile sampling, *per se*, is discussed briefly in Appendix C.)

The specific objectives in monitoring the SO_2 impact of isolated point sources, regardless of terrain setting, are to:

- determine the short-term maximum concentrations downwind of the source and where they occur. (Samplers may be placed where the highest peak is likely to occur and where relatively high peaks are likely to occur very often. It can be assumed that the annual standard will not be threatened by emissions from an individual <u>isolated</u> source.)

- determine the background concentrations by establishing a monitoring site in the direction from the source opposite to those above.

The major problem is to account for the effects imposed by the various terrain settings in determining where to place the monitors to measure the peak values. The terrain settings addressed below are: flat, near coastline, ridge-valley, and irregular-rugged.

4.6.1 Monitoring in Flat Terrain Settings

The recommended procedures in this situation are very similar to those given in EPA (1974b). Plumes behave rather well in this kind of setting and are amenable to treatment with standard diffusion equations.

The first step is to assemble the background information. It should include:

- USGS maps of the area.

- Physical data from point source:
  - peak daily mean production rates of SO_2,
  - stack parameters,
  - exact plant location.

- Stability wind roses (climatological).
- Wind persistence tables.

} See Appendices A and B.

The next step is to confirm that the terrain is flat so that the recommended siting techniques are applicable. The terrain is deemed to be flat if:

- Terrain elevations more than 2/5 the height of the stack do not exist within 10 km of the source (EPA, 1974c).

4.6.1.1 Peak Concentration Stations

After determining that the terrain is flat, a determination must then be made whether the source should be monitored. A screening technique suggested by the EPA (EPA, 1974b, Appendix C) is also suggested here for this purpose. If the technique indicates that monitoring need not be undertaken, check for the possibility of downwash situations occurring. Downwash is likely to occur if:

- the heights of any buildings and other obstructions that exist within a distance of 10 stack heights of the source exceed 2/5 of the height of the stack.

Downwash conditions may also result if the ratio between the stack gas velocity (V_S) and the wind velocity (V) is less than about 1.5. In this case, the effective stack height would be no more (and probably less) than the physical stack height and ground-level concentrations would increase. To assess this, one can do an analysis similar to that described in Section 4.5.2 to estimate the frequency of downwash conditions. Vary the production rates (and V_S) and then compare V_S to the wind speed frequency (see Table 4-6, Page 57) expected over the area to estimate an expected frequency of downwash conditions. Then determine the expected ground-level concentrations by assuming that the effective stack height equals 1/2 of the physical stack height. If the resulting concentrations exceed the threshold concentration prescribed in the screening technique, then use mobile sampling when downwash conditions are predicted. Permanent monitoring sites may be located in "favored" areas if the mobile sampling results show ground-level peaks consistently occurring in about the same place. Site characteristics, etc. are discussed in Section 4.6.1.5.

If a need for monitoring has been determined by the screening technique, but not due to downwash conditions, the estimated locations of the peak 24-hour and 3-hour maximum concentration points can be determined by a technique suggested in Appendix B, Part II for isolated point sources. From Appendix B, Part II, and/or from downwash analyses, then, we have determined the approximate locations of:

- the near-worst 24-hour average concentration,
- the near-worst 3-hour average concentration,
- where a very high concentration occurs very often.

4.6.1.2 Background Stations

The locations of the background stations should be selected to measure the quality of the incoming air. The difference between this background concentration and the peak concentrations measured downwind of the source is equal to the contribution due to the source alone. Background stations should be located:

- in the direction from the source opposite the peak concentration stations, These sites should be located within a few kilometers of the source. Figure 4-21 illustrates a possible monitoring site configuration around an isolated point source in flat terrain.

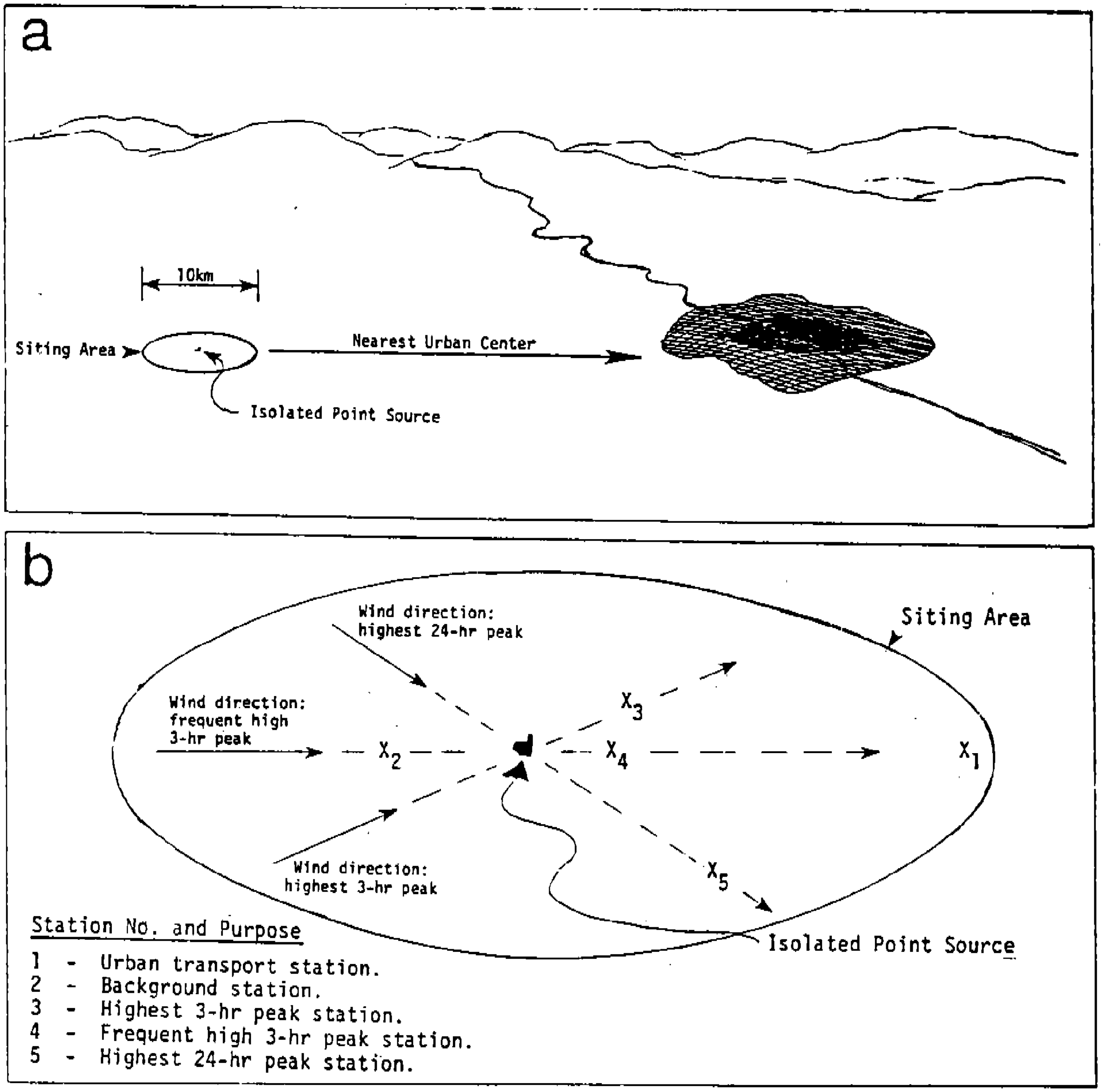

FIGURE 4-21. Illustration of possible monitoring site configuration around an isolated point source in flat terrain; (a) relationship to local geography, and (b) blowup of siting area.

4.6.1.3 Fumigation Effects

It is possible that the highest 3-hour concentrations result from "fumigation". This phenomenon usually occurs as a result of inversion "breakup" after sunrise. Because of the flat terrain and the characteristic light and variable wind conditions associated with such a situation, it is unlikely that a single stationary sampling site could be established for the sole purpose of measuring such concentrations. The recommendation is to use mobile sampling when fumigation is predicted to occur. It is also likely that at least one of the other sampling stations will detect the phenomenon occasionally. Several analysis techniques for estimating fumigation concentrations and where they occur are available--e.g., see EPA (1974c), Turner (1974), and Slade (1968).

4.6.1.4 Role of Mobile Sampling and Final Site Selection

The above procedures can only approximate the location of the peak concentration points because:

- The available meteorological data may not be exactly representative of conditions in the vicinity of the source (main reason for erecting meteorological towers).

- For a given wind direction and stability class (from a stability wind rose) the frequency of wind speed events is reported as occurring within a <u>range</u> of speeds. This wind speed range would correspond to a <u>distance range</u> along the azimuth.

- Diffusion equations are only accurate to within a factor of two or so.

Accordingly, terrain roughness and road accessibility permitting, mobile sampling should be utilized to refine the site locations, particularly those for the 3-hour peak stations. When the meteorological conditions that produce the peak concentrations are predicted, the mobile unit can be dispatched. After a number of occurrences, a plot of observed peak concentration points could probably be enclosed by a circle of middle-scale dimensions (up to 500 m in diameter); the final site should be located near the center of the circle.

4.6.1.5 Site Characteristics and Inlet Placement

The site characteristics and inlet placement for these sites are similar to those for regional monitoring stations. Since the topography is flat, low lying areas should not be a problem; in any case, they should be avoided. Open or sparsely forested areas are recommended with the instruments housed in either a trailer or other stationary structure. Inlet height should be no higher than about 3 to 5 meters. If any buildings in the vicinity are heated by fossil fuels, be sure that they are not between the monitoring site and the source. Otherwise, such buildings and clumps of trees create little cavity wakes which tend to increase the effective sampling volume of the instrument.

If locating a site in a densely forested area is unavoidable, the inlet tube should be raised a few meters above the tops of the surrounding trees. Locate on the lee side of clearings, if possible.

4.6.1.6 Instrument Type and Supplementary Instrumentation

Since we are concerned with the short-term peak concentrations, continuous instrumentation will be required at all stations. Instrumented towers for measuring pertinent meteorological variables, such as temperature lapse rates and wind variation with height (also, air quality as well), are often constructed in the vicinity of a large source or source complex (Munn and Stewart, 1967). They are usually required in situations where the available meteorological data is not representative of the source area, as is often the case in conjunction with the preparation of environmental impact statements (EIS) prior to the construction of large sources. Gill, et al. (1967) and the AEC (1972) describe optimal design configurations for towers and how resulting data should be interpreted, respectively.

4.6.2 Monitoring in Near Coastline Settings

When a tall stack is located near a seacoast or other large body of water such that sea or lake breezes may influence the SO_2 plume, a phenomenon known as a "sea-breeze fumigation" may occur. It results when the stack plume, initially embedded in a stable, sea-breeze flow is convectively mixed down to the ground downwind. The mixing is caused by a vertically growing mixing layer resulting from the stable marine air being heated from below by the land surface as it moves inland (van der Hoven, 1967).* An effort to model fumigation occurring inland from a large lake has recently been reported by Peters (1975). Figure 4-22 is a schematic illustrating the phenomenon. Unlike fumigation resulting from a nocturnal radiation inversion, which might only last for about a half-hour or so, sea-breeze fumigations may last for several hours due to the constant replacement of stable air by the on-shore flow. These short-term sea breeze fumigation concentrations may very well exceed those observed over flat terrain away from marine influences and, therefore, should be monitored, either with appropriately placed permanent stations, or via mobile sampling.

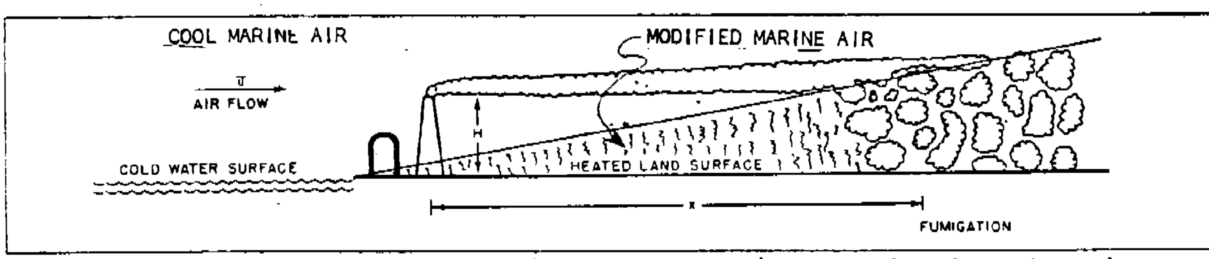

FIGURE 4-22. Schematic illustration of a sea-breeze fumigation situation (taken from Van der Hoven, 1967).

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* In actuality, this phenomena may occur in any on-shore flow if the associated marine air becomes less stable as it moves inland over a heated ground surface.

A recommended procedure for such monitoring is presented below. It is based on the results of a study by Collins (1971) in which the occurrence of sea-breeze fumigations and where they occurred were accurately predicted. The concept is essentially universally applicable except where the coastal topography is extremely rough. The procedure also requires that mobile sampling be utilized. As an illustration of the procedure, consider a plume embedded in a layer of cool marine air at an elevation of 100 meters and moving inland. Data from the 100-meter level (the same elevation as the plume) of an instrumented meteorological or TV tower (or equivalent) are assumed to be available as well as sea-surface temperatures (either estimated or specially taken). For the next series of steps, refer to Figure 4-23 for flat terrain or to Figure 4-24 for rising terrain (height of terrain is subtracted from height of plume above MSL). From the tower data and sea-surface temperatures, the following values are computed:

- $\Delta\theta$ (potential temperature difference) - the 100-m temperature (°C) + 0.91°C* minus the sea-surface temperature (see Figure 4-25).

  $\Delta\theta$ indicates the stability of the layer between plume height and the ground with higher values indicating the more stable conditions. The more stable the atmosphere, the longer it takes for the mixing layer to grow and farther inland the plume will advance before intercepting the mixing layer.

- $\bar{u}$ The mean wind speed within the layer of interest (the wind speed observed at the 50-m level).

  $\bar{u}$ indicates the mean wind speed at which the plume and the stable air is transported inland. The slope of the upper boundary of the mixing layer to the terrain is related to this speed; i.e., at a very low wind speed the mixing layer would intercept the plume relatively close to its source (everything else being equal).

Then, from Figure 4-23 or 4-24, the distance to where the plume intercepts the mixing layer and, therefore, to the initial point of plume touchdown (fumigation) is ascertained (typically, ~0.2 to 2.0 km from the source). In a sea-breeze situation, the direction toward which the plume blows is usually a compromise between the direction normal to the mean shoreline orientation and the flow dictated by the large-scale pressure field. If the wind direction at the 50-meter level on the tower is available (after the sea-breeze has passed), this could be used. The point defined by the distance from the source to where the fumigation is predicted to take place and the 50-meter wind direction could be considered the initial starting point of a search for the maximum fumigation concentration via mobile sampling. In this instance, a vertical sensing capability would be quite helpful.

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* 0.91°C is the adiabatic temperature change that a parcel of air will undergo when brought down to the surface from a 300-ft (100-m) elevation.

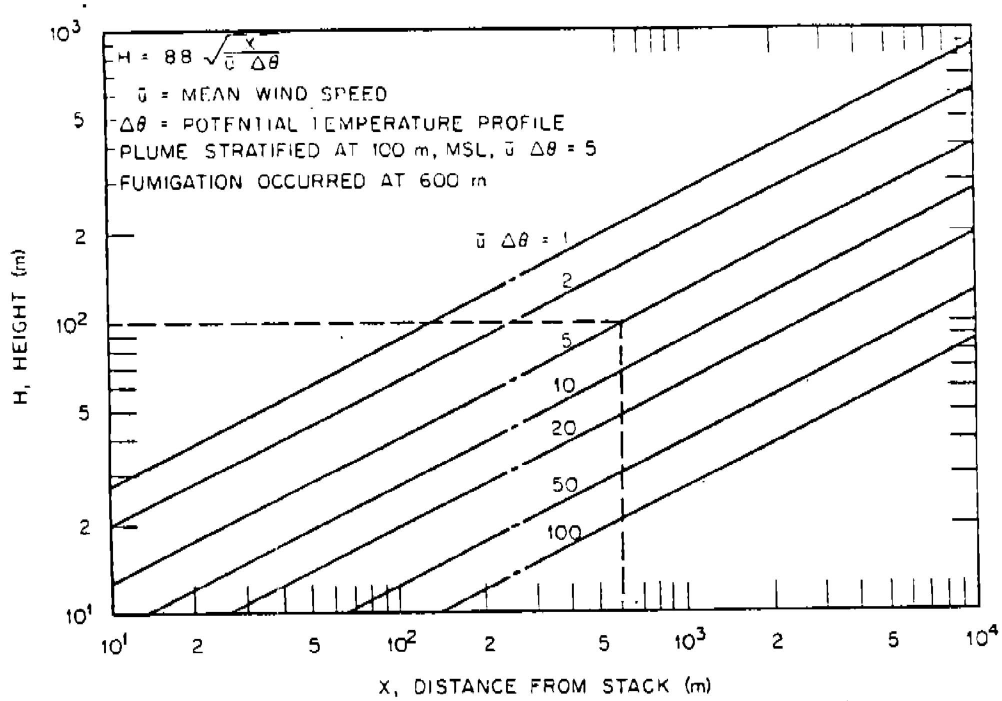

FIGURE 4-23.

Mixing depth as function of stability, wind speed, and inland travel distance (taken from Collins, 1971).

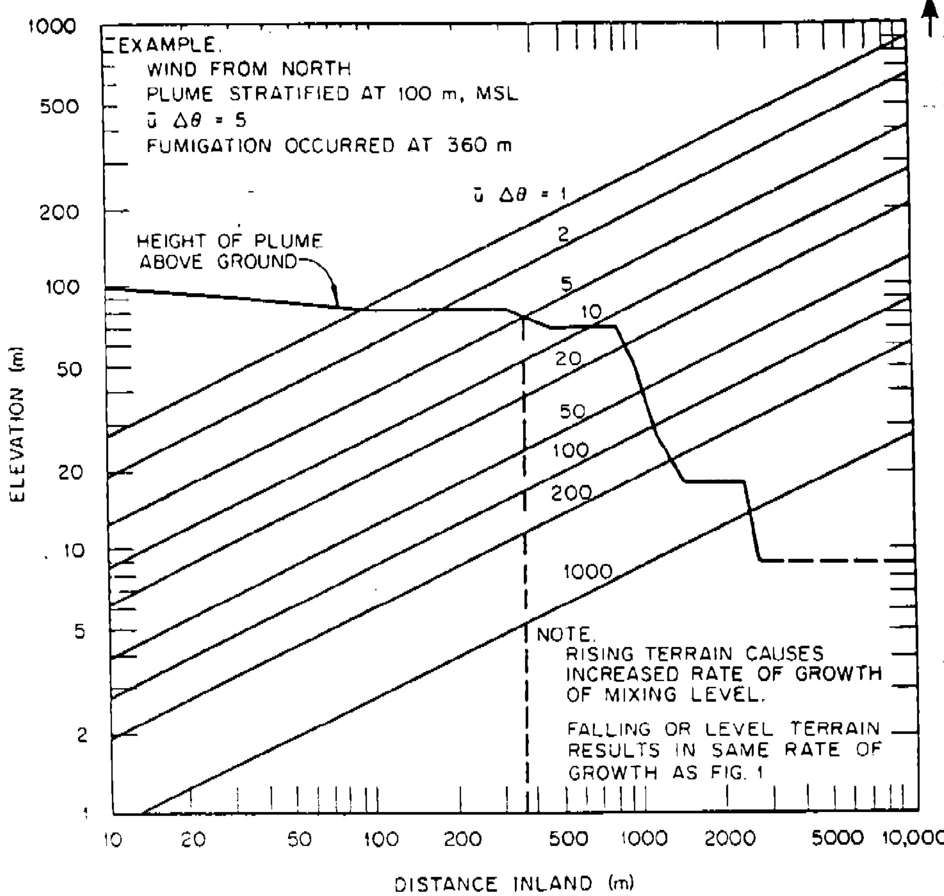

FIGURE 4-24.

Vertical mixing depth adjusted for terrain (taken from Collins, 1971).

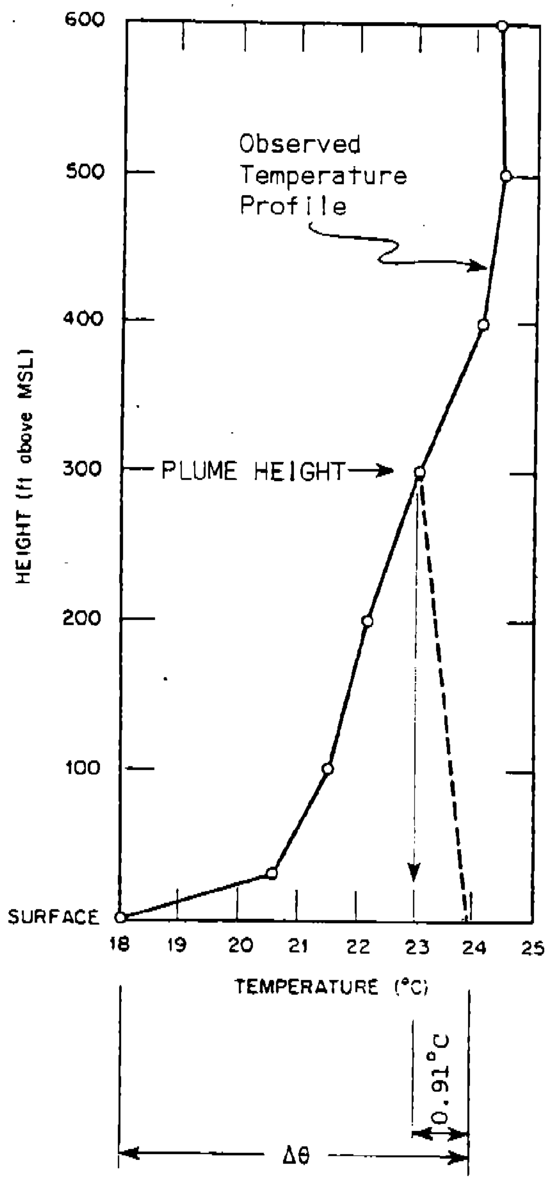

FIGURE 4-25. Example of computation of Δθ (adapted from Collins, 1971).

Regarding a permanent station, it would be feasible to establish one only if the plume tended to touch down within "favored" areas.

Over flat terrain, the monitoring of the sea-breeze fumigation phenomenon would be in addition to the monitoring objectives described in Section 4.6.1. In practical applications of the procedure, there is a problem of obtaining temperatures aloft at plume height (effective height). In the illustration (Figure 4-25), the temperature sensor was exactly at plume height--an ideal situation not likely to be encountered in the field. Figure 4-23 is universally applicable in flat coastline topography if temperatures are taken at effective plume height. Figure 4-24 would have to be modified to reflect the slope of the ground in the coastline area of concern. In all situations, the services of a diffusion meteorologist is strongly recommended.

4.6.2.1 Site Characteristics and Instrument Inlet Placement

In the event that a favored area does exist--i.e., a small area over which fumigation occurs--the site characteristics and inlet placement should be the same as those for the flat terrain stations (see Section 4.6.1.5). In irregular, rough terrain areas, choose well exposed locations.

4.6.3 Monitoring in Ridge/Valley Settings

This kind of terrain is found mainly in the Appalachian Mountain area and in parts of the upland region of several of the western states. For purposes of this discussion, characteristics of such areas are, typically, a valley of arbitrary width with parallel walls or ridges and a more or less definable "up-valley/down-valley" direction.

Because no two ridge/valley configurations are exactly alike, a detailed treatment of the subject is difficult and the development of siting procedures uniform for all possible scenarios is impractical. (For a detailed discussion of the subject of plume behavior in valleys, the reader is referred to the work of Hewson, et al., 1961; Smith, 1968; and Flemming, 1967.) However, from the descriptions provided by these references, typical situations were derived from which a general procedural guideline for siting monitors was developed. The situations include the likely kinds of impacts expected to result from a large, elevated point SO_2 source located in a valley with steep walls and under a variety of meteorological conditions. The kinds of SO_2 problems associated with such a scenario will be briefly summarized below, and followed by recommended siting procedures.

4.6.3.1 SO_2 Problems

- "Fumigation" occurring shortly after sunrise (see Figure 4-26). A plume may be embedded in a down-valley drainage flow then brought down to ground level after sunrise via the fumigation mechanism.

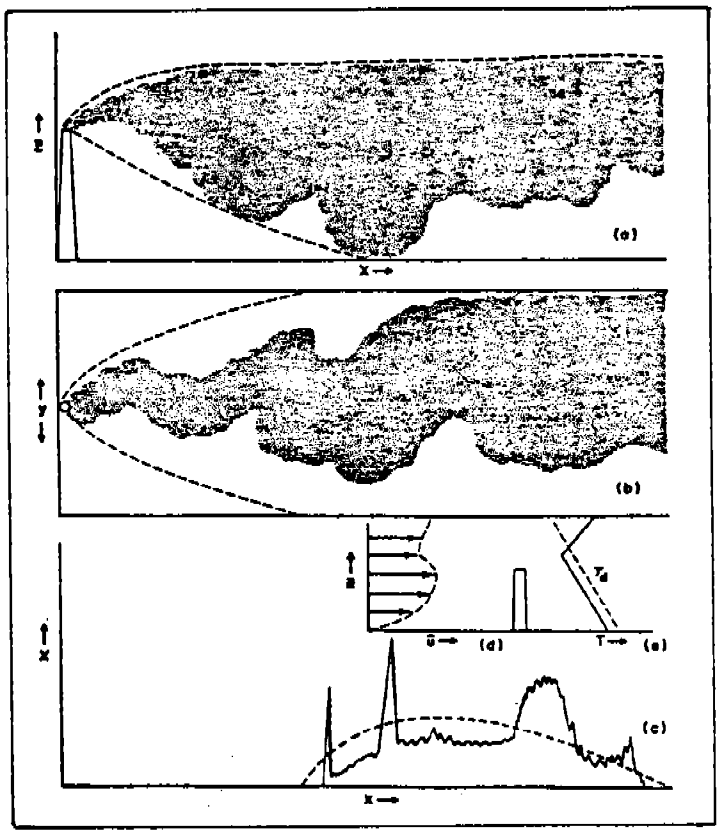

FIGURE 4-26. Inversion aloft-above stack ("fumigation"), (taken from ASME, 1968).

- Near intersection of plume with valley wall with a cross-valley wind flow under stable to unstable conditions (see Figure 4-27).

- Distortion and downwash of the plume due to wake effects on lee side of upwind wall (see Figure 4-28).

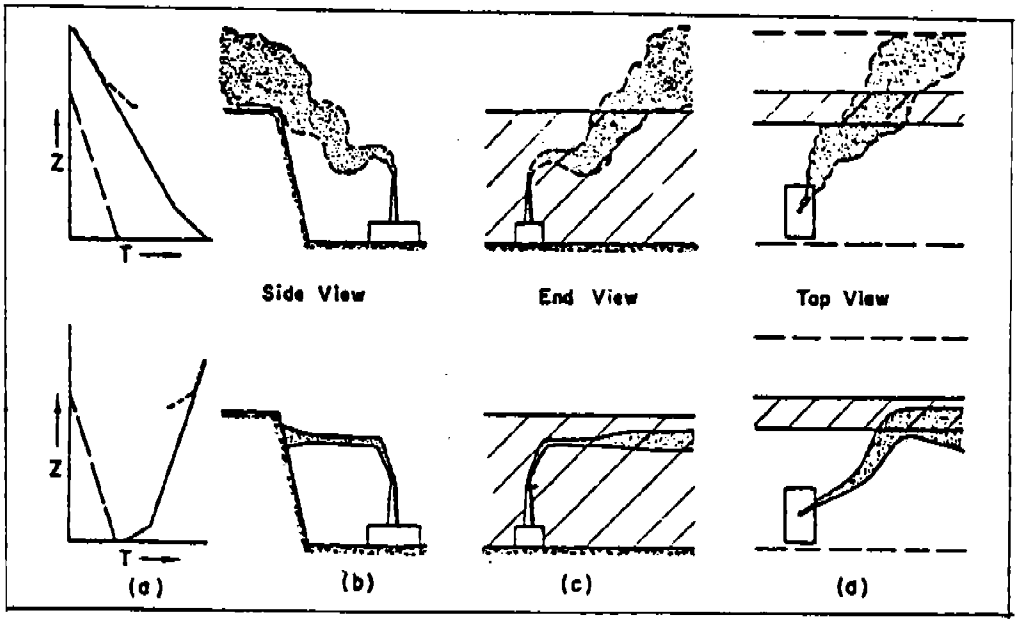

FIGURE 4-27. Plume behavior near a steep bluff when the air is unstable(above) and when it is very stable(below). (a) Vertical temperature lapse rates in relation to the critical lapse rate of 5°F/1000 ft, shown by broken line sloping upward to left: full line--lapse rate measured from grade at plant; dotted line--lapse rate measured from top of bluff; both show effect of ground surface. Corresponding plume features as observed (b) looking horizontally parallel to steep bluff, (c) looking horizontally toward steep bluff, and (d) looking vertically downward from above. Note that when air is unstable, effluent moves up and over the bluff, but when the air is very stable, as with the inversion as shown, the bluff acts as a barrier to deflect the plume. (Taken from Hewson, et al., 1961.)

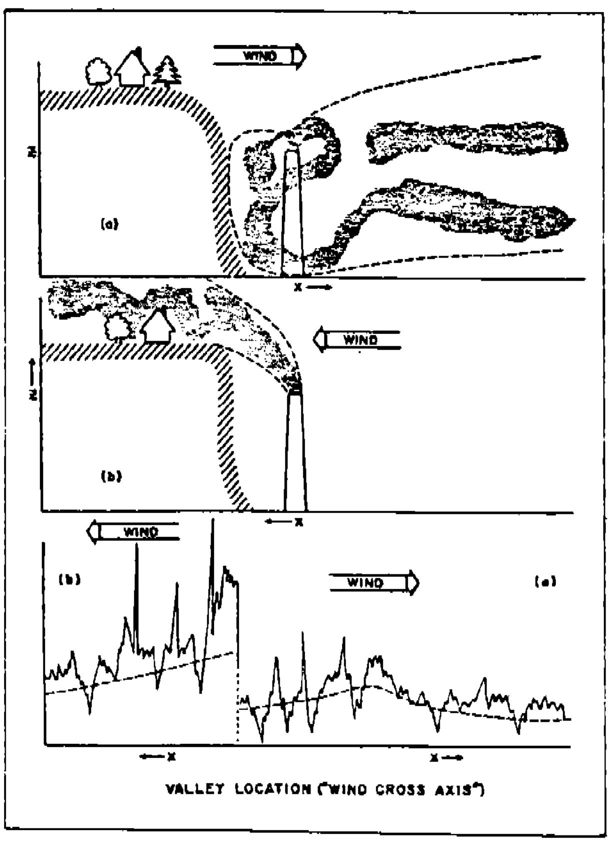

Figure 4-28.

Plume dispersion in a deep valley. With a wind from left to right, as in Section (a), the plume may be brought quickly to ground level by aerodynamic eddies. Wind from the opposite direction may create high concentrations on the plateau. (Taken from ASME, 1968.)

- Maximum impact points at ground level in the valley when wind direction is parallel to valley (see Figure 4-29).

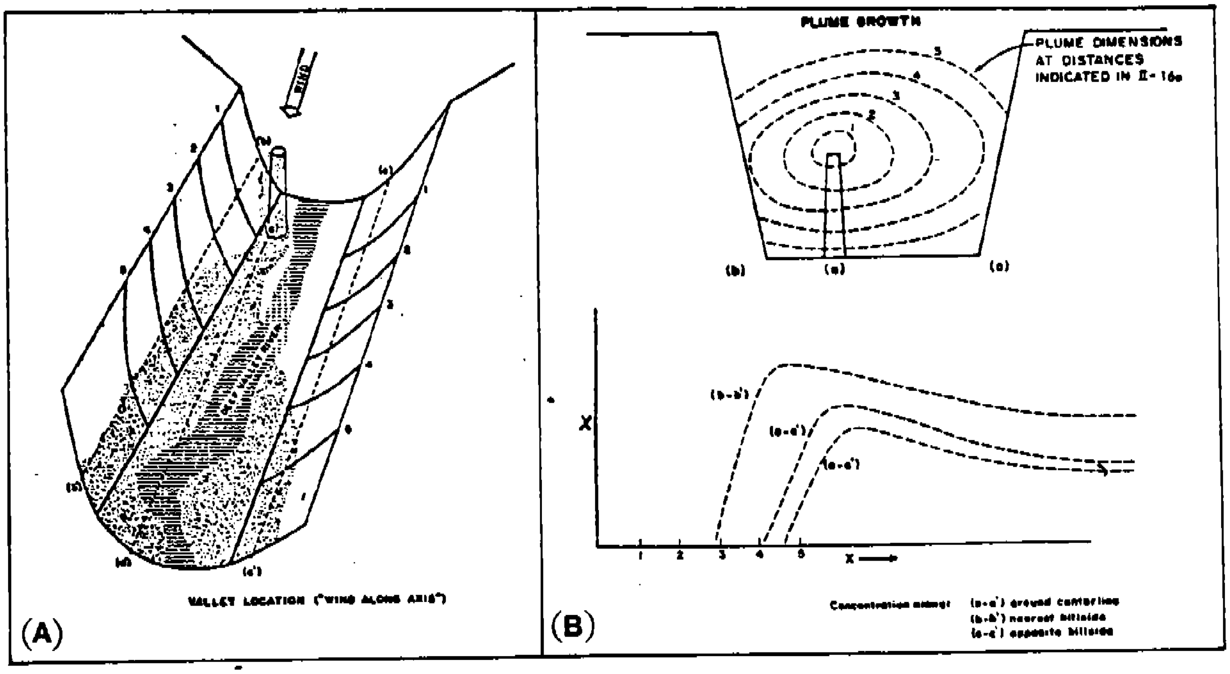

FIGURE 4-29. Plume dispersion in a deep valley. When the wind is parallel to the valley, dispersion tends to occur fairly normally until confined by the valley walls. Section (A) is a pictorial representation of the dispersion; Section (B) shows the associated concentration patterns. (Taken from ASME, 1968.)

4.6.3.2 Siting Procedures.

The first step common to any monitor siting study in this kind of terrain is to acquire supporting data, information, and equipment such as that listed below:

- USGS map of area.
- Physical data from the SO_2 source
  - peak and daily mean production rates,
  - stack parameters,
  - exact plant location.
- Stability wind rose (climatological) } See Appendices A and B.
- Wind persistence tables } See Appendices A and B.
- Portable wind measuring system.
- Smoke bombs.

- Mobile sampling system.

- Cameras.

If the meteorological data originates at an observing site located on the high terrain outside of the valley,* adjustments of the wind data will be necessary because of the channeling effect of the valley (a meteorologist should be consulted to determine these adjustments)

4.6.3.2.1 Fumigation Concentration Stations. Fumigation situations in valleys usually occur under inversion break-up conditions (e.g., see Hewson and Gill, 1944). Winds are often calm or variable at typical airport locations (higher terrain). However, down in the valley drainage and valley flows may carry plumes down the valley (see Figure 4-30). Since there may be little or no correlation between airport winds and valley winds in these situations, it is suggested that plume behavior (e.g., typical direction of movement) be determined through visual observations via photography, smoke bombs, or photographing the panorama from a ridgetop vantage point. If the plume follows a similar trajectory--e.g., consistently downvalley--whenever an inversion situation occurs, it may be possible to site a monitor in a permanent location (see Figure 4-31a). While data for developing the plume "climatology" is being gathered (photographs, etc.), mobile sampling could be conducted to determine fumigation concentrations and where the maxima are typically located; again, a vertical sensing capability would be quite useful. Permanent sites could be located if "favored" areas are observed, otherwise mobile sampling may have to be conducted routinely. As an option, fumigation concentrations may be calculated (by procedures as discussed, for example, in EPA, 1974c) to estimate the maximum expected concentrations and the distances downwind where they theoretically should occur. The 3-hour peak concentration is the averaging time of concern.

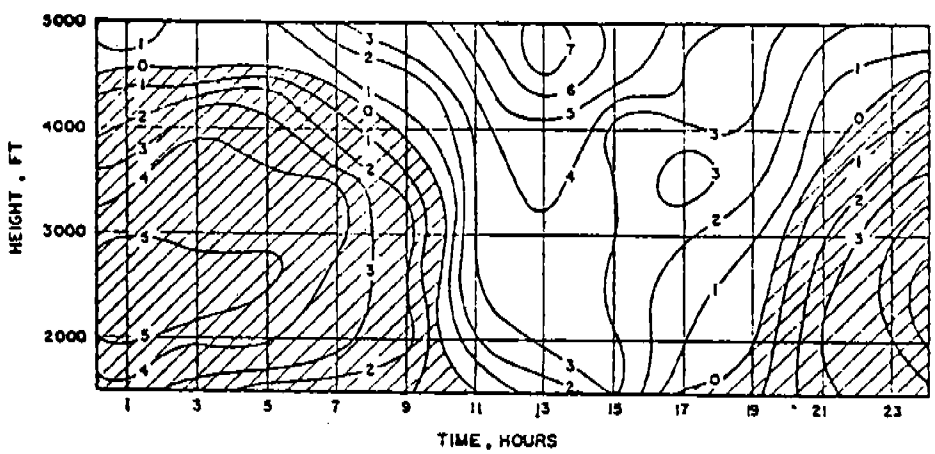

FIGURE 4-30. The diurnal variation of valley winds during the summer in the Columbia River Valley near Trail, B.C. Isopleths give average wind speed components (mph): hatched areas - downvalley (north); unhatched areas - upvalley (south). (Taken from Hewson, et al., 1961.)

* For purposes of discussion, assume that such an observing site is a first order NWS airport weather station taking regular observations.

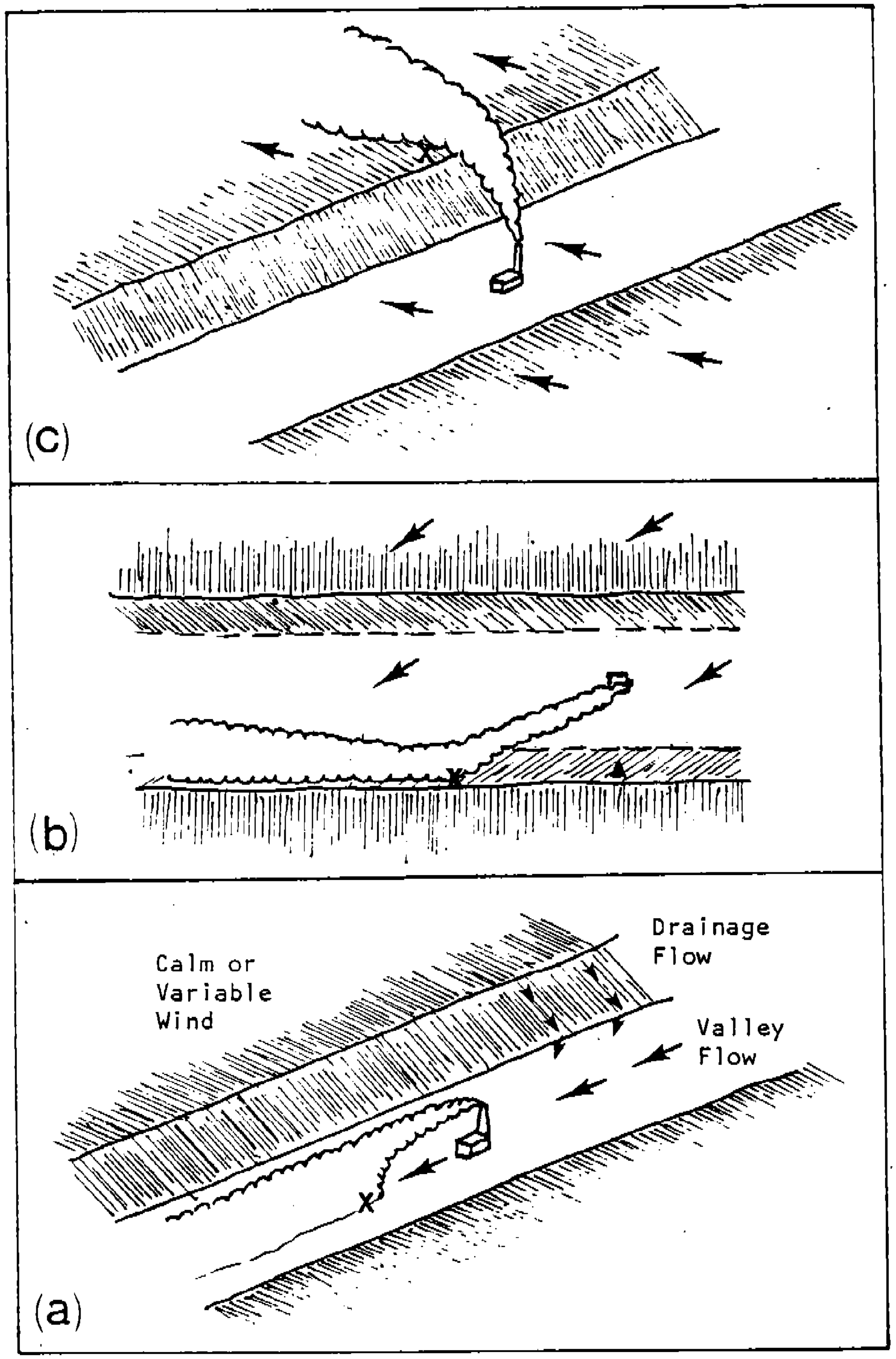

FIGURE 4-31. Illustration of plume configurations under a variety of meteorological conditions and relative locations of sampling sites (X); (a) fumigation situation, (b) plume deflected by valley wall (channeled flow in valley), (c) plume either deflected over wall under unstable conditions or passing out of valley due to excessive plume rise. Symbol ▲ is location at point on wall nearest the source (downwind wall).

4.6.3.2.2 Valley-Wall Impact Stations. When the large-scale wind blows in a cross-valley fashion, the valley wind direction is often channeled; i.e., the resulting direction on the valley flow is a compromise between the large-scale flow direction and the valley orientation. Depending on the wind speed, direction, and stability, the plume may either pass over the valley wall or interact with it (not impinge upon it) and move downwind along it. Under stronger winds, aerodynamic downwash conditions may prevail.

A wind station will need to be established on the valley floor; utilizing the services of a meteorologist, determine the wind climatology on the valley floor for various speed ranges and stability classes. From wind climatology, several basic valley-wall impact situations can be deduced. These situations are listed below along with recommended siting procedures, or points to consider for siting monitors, mainly for measuring 3-hour impacts.

- Stable to unstable conditons, light to moderate winds, high terrain (airport); channeled wind in valley.

  In this situation, we are assuming that the plume will not, in the case of the stable conditions, clear the top of the valley walls; neither will it intersect it but will approach, then be deflected by it and move along downwind parallel to it (see Figure 4-31b). To assess this situation, the first step is to determine the most frequently occurring wind direction at the airport (from its stability wind rose) for stable conditions and determine the associated valley resultant direction.* This direction is the vector sum of the valley flow wind direction and airport wind direction. This direction defines the azimuth of "intersection" with the valley wall. A tentative siting area should be established above the half-way point between the valley floor and top of the wall where the azimuth intersects the valley wall (see Figure 4-31b). The final site should be selected on the basis of visual observations. Caution should also be exercised regarding possible prolonged and continuous downwash conditions; cavity flows on the lee side of the upwind wall may distort the plume near its source.

  Under unstable conditions, the plume will either be deflected over the valley wall rather than along it, or will pass out of the valley without any significant impact as shown in Figure 4-31c. (See Appendix E for available models that can deal with such situations.)

- Stable conditions, light (not variable) cross-valley wind at the airport; drainage flow in valley.

  This situation is very similar to the one above except for the following points:

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* The valley resultant direction as used here is an estimate of the direction between the source and the closest approach point of the plume to the valley wall (or "impact" point). Visual confirmation is recommended.

- To estimate the azimuth of intersection in this case, the valley resultant direction is considered a compromise between the <u>valley orientation</u> and the airport wind direction.
- Also, since the winds are light, the effective height of the plume may be above the valley wall and pass out of the valley with reduced impact at the valley wall and beyond (see Figure 4-31c).

Visual observations and the use of standard diffusion equations, making the proper adjustments for terrain elevation (see Appendix E for available models), should be made to determine degree of impact and direction of plume movement under such circumstances. If plume does not clear valley wall, then the problem is similar to that above (see Figure 4-32a).

- <u>Neutral or unstable conditions, moderate to strong winds at the airport; cross-valley direction.</u>

  Under this situation, the plume is expected to be subjected to downwash conditions due to either wake effects on the lee side of the upwind wall or to the contravention of the 1.5 V_S/U ratio rule or both. In this instance, siting procedures are difficult to generalize. However, suffice it to say that the highest concentration would occur near the stack and measured most effectively via mobile sampling. Even in this case though, if favored plume touchdown areas are observed, this would provide a basis for establishing a permanent station (see Figure 4-32b). Guidance for analyzing the 1.5 ratio rule contravention problem was discussed in Section 4.5.2.

<u>4.6.3.2.3 Worst-Case Conditions for Along Valley Flow</u>. This situation can be handled in a manner similar to that for the flat terrain case for both 24-hour and 3-hour average impact assessments. However, a meteorologist should be consulted for advice. Locate tentative 3-hour and 24-hour peak monitoring sites using the procedures discussed in Section 4.6.1. Finalize location via mobile sampling. See Figure 4-32c for illustration.

<u>4.6.3.2.4 Supplementary Monitoring Stations and Concluding Comments</u>. In all situations, one site should be established at a point nearest the source on the wall most frequently downwind (based on annual wind rose) and one background site located a kilometer or so upvalley from the source. Instrument types, inlet placement, site characteristics and supplementary equipment for all stations are the same as those discussed in Section 4.6.1. If instrumented towers are erected, the elevated point source-in-valley situations and related monitoring site selection problems can be treated in a manner more rigorous than that described above.

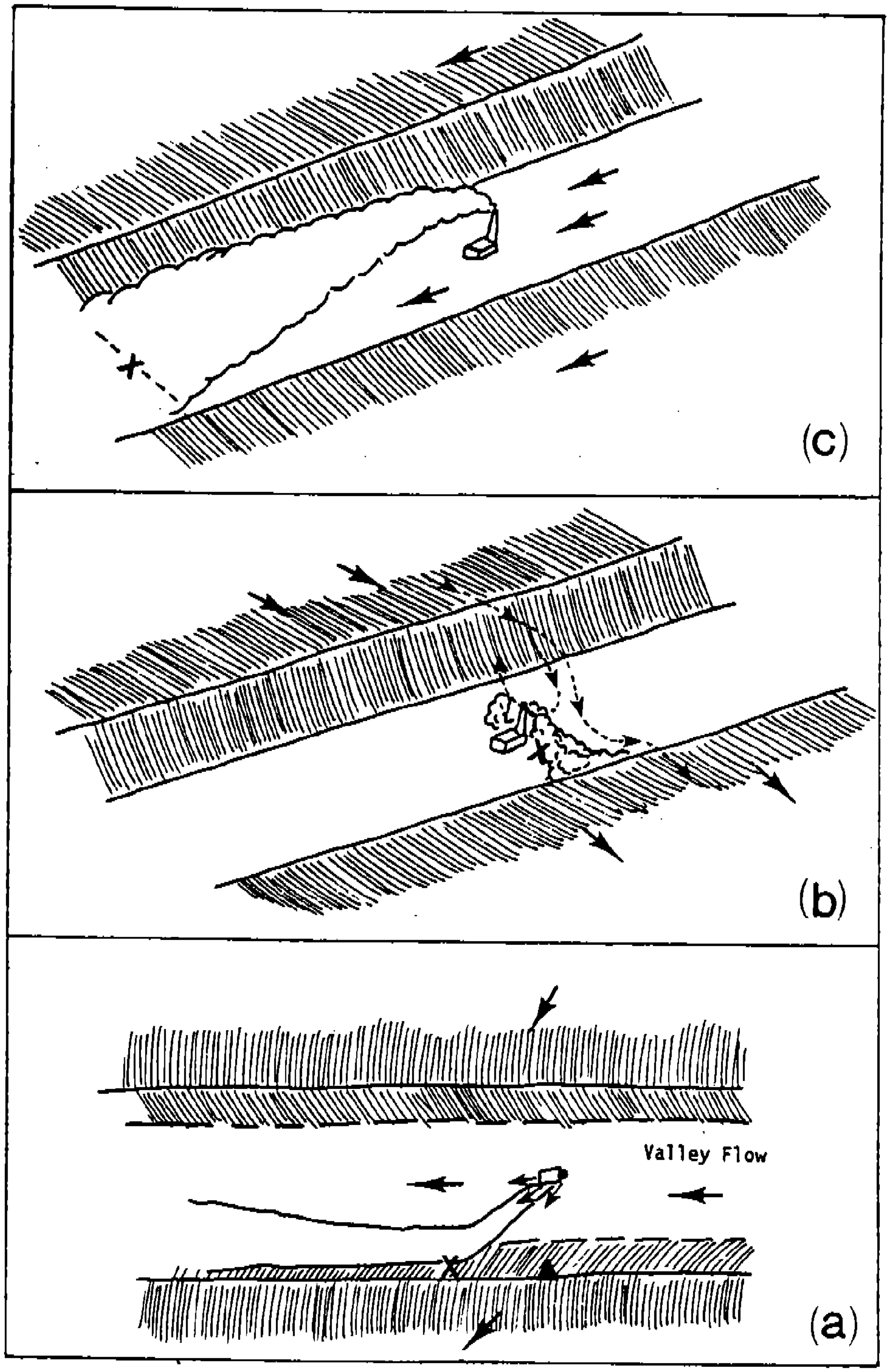


FIGURE 4-32. Illustration of plume configuration under a variety of meteorological conditions and relative locations of sampling sites; (a) plume deflected by valley wall (calm or valley wind in valley), (b) plume influenced by wake effects, and (c) maximum concentration configuration in valley with along-valley flow.

4.6.4 Monitoring in Rough, Irregular Terrain Settings

Rough, irregular terrain may range in texture from nearly flat to extremely severe (e.g., the mountainous areas of Idaho, Utah, etc.). Since this terrain is "irregular" by definition, no typical setting exists. Thus, we were considerably hampered by this situation in that it did not permit us to develop a "typical" scenario from which a site selection rationale or methodology could be presented, as, for example, in the previous discussion. However, we dealt with the problem by separating the terrain type into two "regimes", one in which the setting was characterized by irregular topographic features of sizes no larger than a typical physical stack height of a point source (roughly 300 ft), and the other which was characterized by larger features, up to and including the extreme mountainous. The former is reasonably amenable to diffusion model analysis in the more or less traditional sense, as for example shown by Leahey (1974). In this regard, as will be seen, the monitor siting approach in this regime can be developed in a manner similar to that described for flat terrain (see Section 4.6.1). However, plume behavior in the latter regime is extremely complex and beyond the simulation capability of most models. For example, two rather detailed tracer studies that were conducted by the National Oceanic and Atmospheric Administration (NOAA) in mountainous terrain in Utah (Start, et al., 1973, 1974) showed the extremely complex behavior of tracer material under various meteorological conditions; the preparation of uniform site selection procedures for achieving specific monitoring objectives in such terrain is clearly impractical. In view of this, it seems likely that any effort short of an individual diffusion study, uniquely designed for a given situation, to assess the SO_2 impact of a new or existing source will probably be unsuccessful, at least in the extreme terrain cases. At the "smooth" end of this rough topographical regime, tracer and numerical meteorological/diffusion modeling have been conducted (Hinds, 1970; and Hīno, 1968, respectively). The reader is urged to consult these and the other references cited above to gain a better insight of the problems of monitor siting in rough terrain. The services of a diffusion meteorologist is also strongly recommended.

4.6.4.1 Monitor Siting Procedures in Terrain of Up to Moderate Roughness

In the context of this discussion, the mean elevations of the terrain are considered to be reasonably level with the maximum deviations from the mean not exceeding a value equal to the height of a typical point source stack. The recommended approach for selecting SO_2 monitoring sites is identical to that for flat terrain; however, the specifics of the approach differ in the following respects.

- Diffusion Coefficients. Because of the mechanical turbulence induced by the rough topography, the graphical solutions to the Gaussian equation--viz., Fig. B-2, Appendix B, Part II--must be modified by incorporating diffusion coefficients appropriate for such terrain. The coefficients suggested by Bowne (1973) for suburban and urban areas seem appropriate. These would correspond to slightly rough (features up to sizes of three-story buildings) to moderately rough (up to stack height) topography. As a more accurate alternative, diffusion coefficients could be derived sepcifically for the area of interest as shown by Leahey (1974).

- Corrections for Terrain Elevation. Because of the scattered and irregular nature of the terrain features, as opposed to a solid barrier to the wind, caution should be exercised in correcting concentration estimates, or in estimating locations of ground-level concentration maxima. The major effect of the terrain on the plume will be to increase its rate of dispersal, which would tend to bring the ground-level concentration maxima closer to the stack. Concentrations would also likely be higher at the top of obstacles. However, a lower level plume (effective H below the tops of the obstacles) would tend to split and move around the obstacle, particularly under stable conditions, resulting in lower concentrations at the top of the obstacle. In more undulating topography, the plume would tend to follow the terrain. However, height corrections would need to be made where the terrain elevation changed abruptly. For example, Figure 4-33 is a numerical model simulation of the ground-level pattern produced by an elevated plume, showing increased concentrations over elevated terrain (Hino, 1968).

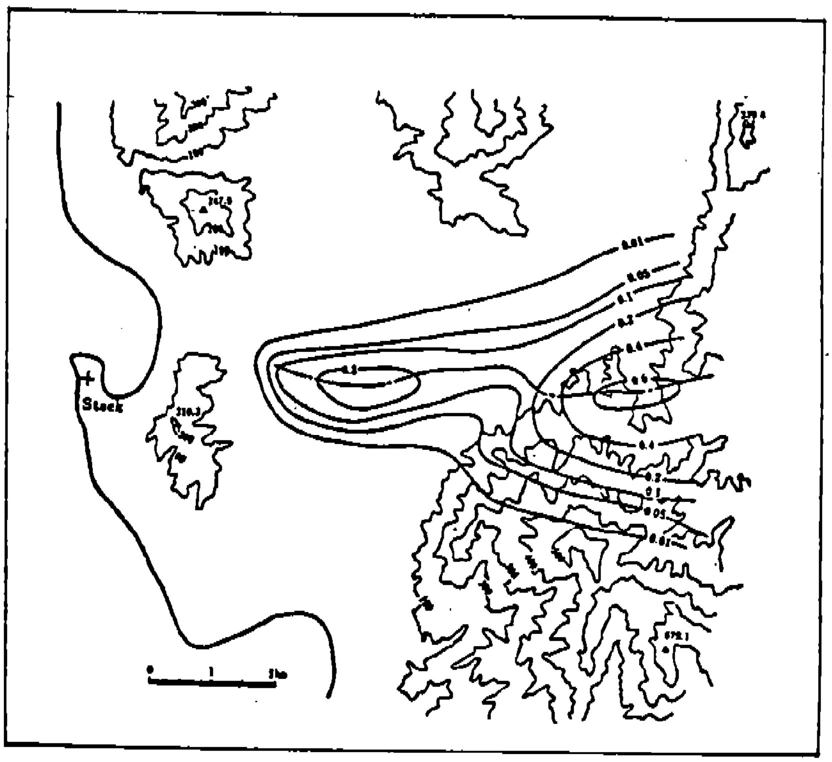


FIGURE 4-33. Distribution at height of 40m from ground surface ($\zeta = z - h =$ 40m) of concentration of smoke emitted from a source with height 400m which is derived from the computer experiment (taken from Hino, 1968).

- Downwash Situations. If obstacles higher than 2/5 of the height of stack exist within 10 stack heights of the stack, downwash due to wake effects is very likely. Downwash analyses, such as those discussed in previous sections, would be necessary.

Taking into account the above points, the procedure discussed in Section 4.6.1 can be utilized in selecting monitoring stations. However, because of the heterogeneous nature of the setting, more reliance on mobile sampling and visual observations of plume behavior may be required.

- General Comments on Site Characteristics. The site characteristics should be similar to those discussed in Section 4.6.1.5. However it is recognized that wake disturbances on the lee sides of obstacles will be the rule. These disturbances, which may extend to twice the height and five to ten obstacle heights downwind, should not be considered as things to avoid entirely. Such obstacles close to a stack may downwash the plume to the ground to complicate the picture. However, if downwash does not occur near the stack, any wake effect produced by an obstacle located near the expected ground-level maximum point would have very little influence on where the actual maximum concentration would be found, since the plume has already diffused down to the ground naturally over an area probably larger in size than the obstacle itself.

4.6.4.2 Conditions in Extremely Rough Terrain

The nature of this terrain precludes the development of monitoring site selection procedures that could be uniformly applied to any given mountainous terrain configuration. However, describing some of the gross characteristics of plume behavior in such terrain may be instructive in terms of "points to consider" when contemplating establishing SO_2 monitoring sites to assess the impact of individual point sources so located.

The following summary was abstracted from the two NOAA studies (Start, et al., 1973, 1974) and from the study by Hinds (1970) cited previously. The studies described the behavior of plumes over specific sections of California and Utah characterized by extremely rough terrain. Plume behavior in these areas may or may not typify such behavior in other similar topographic areas.

- Elevated Plume. Centerline concentrations are reasonably well predicted by the standard Pasquill-Gifford diffusion curves when the plume does not pass over mountainous terrain. However, over mountainous terrain elevated centerline concentrations average from 3 to 4 times more dilute.

- Lateral Plume. Spreading is almost twice that expected for over flat terrain. Several physical processes contribute to this increased spreading.
  - Plumes tend to be deflected around obstacles.

- The descending portions of looping plumes spread laterally as they approach steeply sloped canyon floors.
- Increased mechanical turbulence enhances lateral spreading.
- Vertical shearing of wind direction with height enhances lateral spreading.

- When a low, strongly stable layer aloft combines with flow-blockage effects of the terrain, a quasi-stagnant air pocket can develop that may contain an elevated plume layer. Prolonged ground-surface contact with this layer is probable.

- A higher stable layer will allow the plume to flow over the ridge-tops and the plume tends to become uniformly distributed in the vertical. Because of ground-reflection effects, ground-level concentrations may be twice as large as those aloft.

- With no stable layer aloft, plumes are deflected aloft over the ridges and follow a path similar to the shape of the underlying topography. The lateral distribution of pollutants from the centerline is generally Gaussian.

- The locations of the maximum ground-level concentrations were at the ridgetops. Specific impact areas were identified best via pilot balloon (pibal) wind observations near the effective plume height.

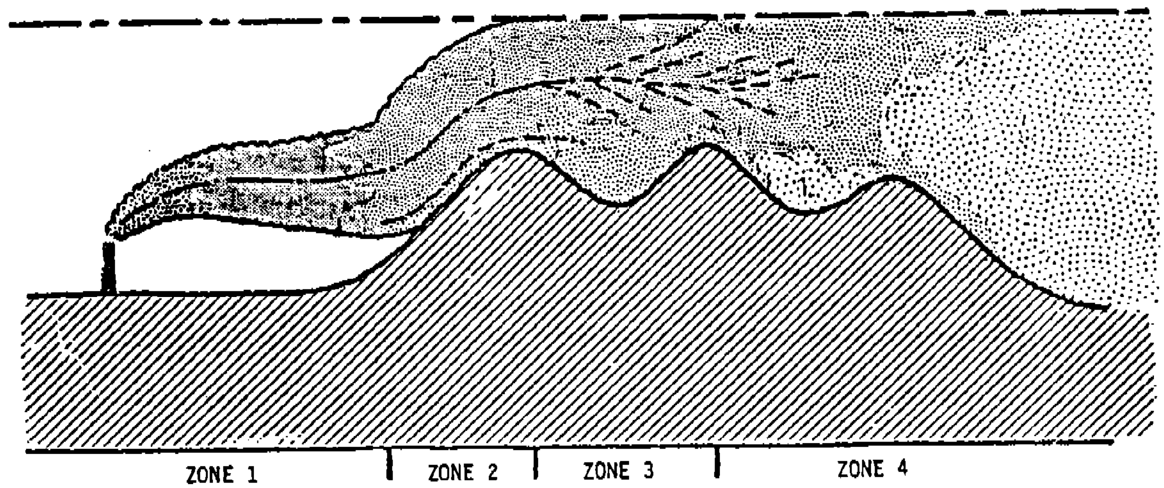
- Figure 4-34 is a schematic illustrating the dilution of an airborn plume as it interacts with elevated, rough topography.

- In unstable conditions rates of dilution in mountainous terrain are about the same as those over flat terrain; the rates increase by a factor of 5 in neutral conditions and a factor of 15 in stable conditions.

- Peak to mean concentration ratios in mountainous terrain are lower than those over flat terrain.

- In canyon settings within mountainous terrain, mechanical turbulence is enhanced by:
  - Turbulence generated near the mountain tops and the upper confines of the canyon.
  - Airflows originating within side canyons.
  - Wake effects of airflows over and around canyon topographic variations.

- Because of strong diurnal wind cycles characteristic of canyon topography, synoptic stagnation conditions are not the worst diffusion conditions.



ZONE 1: "Simple" elevated plume with buoyant rise, becoming the bent-over form. Near Gaussian vertical distribution.
ZONE 2: Deflection zone with plume tending to parallel ground surface. Near Gaussian vertical distribution.
ZONE 3: Mixing or transitional zone affected by turbulence about the topography. Quasi-Gaussian vertical distribution.
ZONE 4: Well-mixed zone. Quasi-uniform vertical distribution of plume mass.

Plume effluent concentrations are greatest where the shading is the most dense.

FIGURE 4-34. Schematic illustration of the dilution of an airborne plume as it approaches and flows over nearby elevated terrain. Four zones of plume behavior and the postulated vertical mass distributions are depicted. (Taken from Start, et al., 1974.)

- Figure 4-35 illustrates the turbulent wake effects of obstacles characteristic of canyon topography.

- Diffusion over a ridge-canyon system often results in substantially lower concentrations on the canyon floor than would occur at the same distance over flat terrain.

4.6.4.3 Implications for SO_2 Monitoring

Based on the above observations, the following general guidelines for selecting SO_2 monitoring sites in extremely rough terrain are suggested.

- In regions subject to at least occasional periods of low mixing depths, locate monitors in basins that have inlets for SO_2 source plumes. Very high concentrations could result from stagnant air pockets that could develop in such areas. The rough terrain, upland areas of the west coast of the United States would seem to be particularly liable.

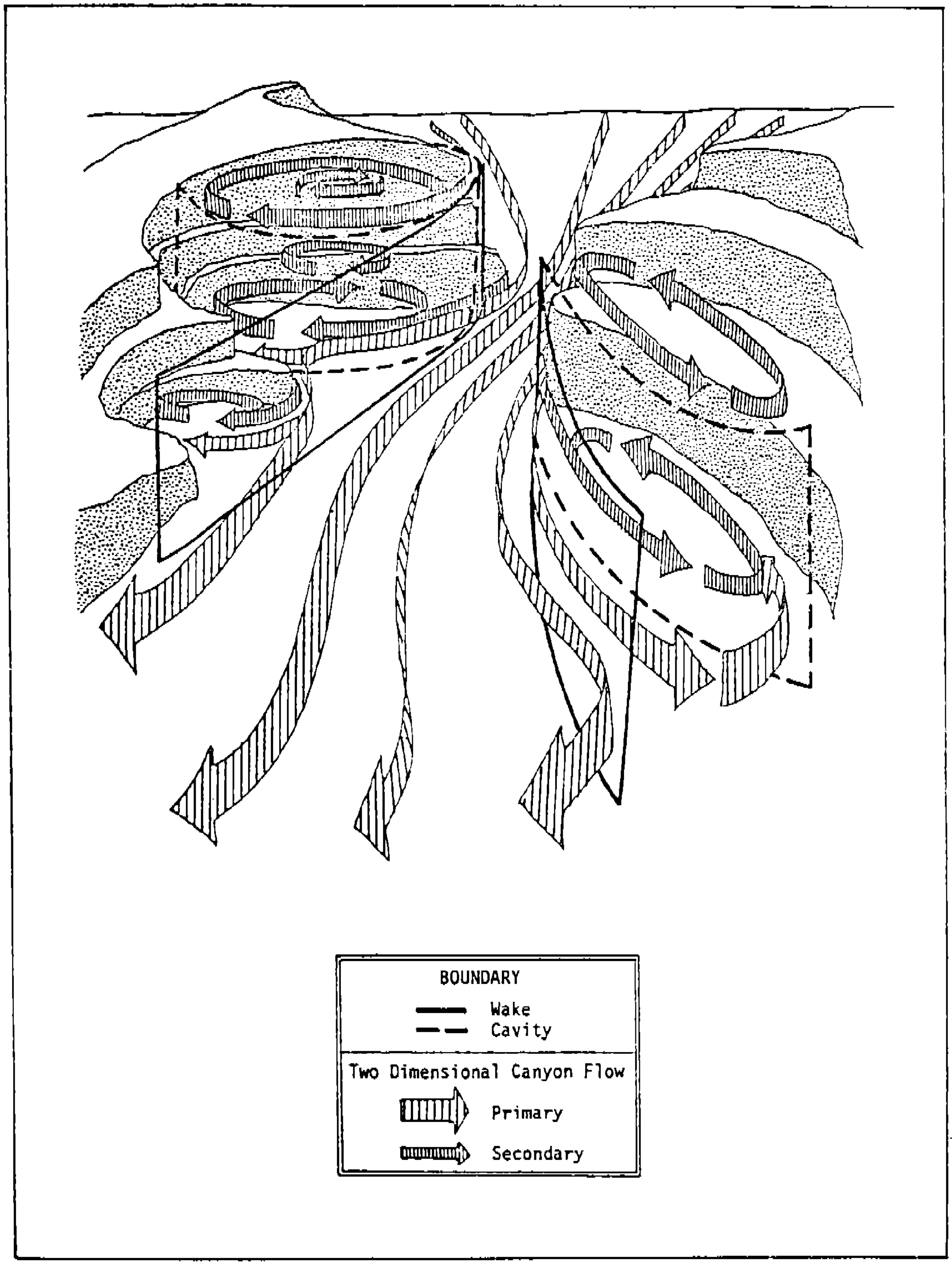


FIGURE 4-35. Schematic illustration of turbulent wake effects caused by obstacles protruding into the primary flow pattern. (Adapted from Start, et al, 1973).

- Site monitors at rigetop locations in the general downwind directions from the source, or perhaps at ridgetop locations surrounding the source, particularly those nearest the source at near effective height (H) elevations.

- Site monitors in passes that may receive the plume advected either by drainage or channeled winds.

- A complete survey of the entire area influenced by the SO_2 source would almost certainly be required in all situations. Visual observations, aerial photography, mobile sampling, remote sensing, etc. would probably be the most important means for conducting such surveys.

5.0 RATIONALE AND SUPPORT DOCUMENTATION FOR SITING CRITERIA

The site selection and inlet placement procedures and criteria discussed in Section 4.0 are quite specific, particularly those regarding location parameters such as height of the inlet, proximities of interfering sources (undue influence) and horizontal positioning of the inlet for rooftop sties, etc. The rationale for some of these procedures and siting approaches was included to explain certain points of the procedural logic. However, it was felt that justifying certain other elements of the siting procedures and criteria would have muddled the continuity. Therefore, we have reserved this section for their presentation.

The logic underlying the procedures of Section 4.0 can be considered embodied in three basic elements:

1) Determining the general location of the monitoring site, mainly via simulation modeling.

2) Refining the location to minimize undue influences from nearby sources, including meteorological effects.

3) Placing the instrument inlet in such a location to avoid local contamination.

The first element, we believe, has been adequately covered in previous sections and in the appendices and requires no further discussion here. Therefore, much of the material presented in this section will pertain to elements 2 and 3. Several miscellaneous items that are relevant to all three elements will also be discussed.

5.1 UNDUE INFLUENCE EFFECTS

Regarding the problem of establishing a site location such that undue influences from nearby sources are minimized,* we had to first define what constituted undue influence. We wanted to use a fairly stable, maximum SO_2 concentration as a level of undue influence and then establish a separation distance between the monitoring site and all sources such that any one source's contribution at the monitoring site would not exceed the undue

* In just about every reference cited in this study the problem of undue influence of nearby sources was mentioned, but no objective procedures or approaches for dealing with such influences were ever suggested.

influence level. Typical rural background levels over all parts of the country seemed to be excessive, 10-30 μg/m^3 (viz., Figure 4-3, EPA,1974d), to be used as an undue influence level for regional-scale stations. Also, these levels were decreasing due to the effectiveness of SO_2 emission controls. Thus, it was decided to use the natural background level of 2.6 μg/m^3 (1 ppb) as reported by Robinson and Robbins (1970), a very low level and probably quite stable as well. Using this value and typical emission rates for various classes and configurations of sources, we determined sets of distances beyond which impacts from any source did not exceed the undue influence level. Examples of these distances, described as "interference distances" (IDs), were shown in Table 4-2 (see Page 34).

The ID of a major urban area was determined by using the normalized concentration pattern resulting from a circular area source as shown in Figure 5-1 (from Ludwig and Kealoha, 1975) along with a speed of 1 m/sec and a half-life value of 3 hours.* Typical maximum emission rates for a major urban area were assumed to be represented by the city of Philadelphia, $Q = 0.86 \times 10^{-5}$ g/sec/m^2 (from EPA,1973b). This gave an ID of about 30 km.

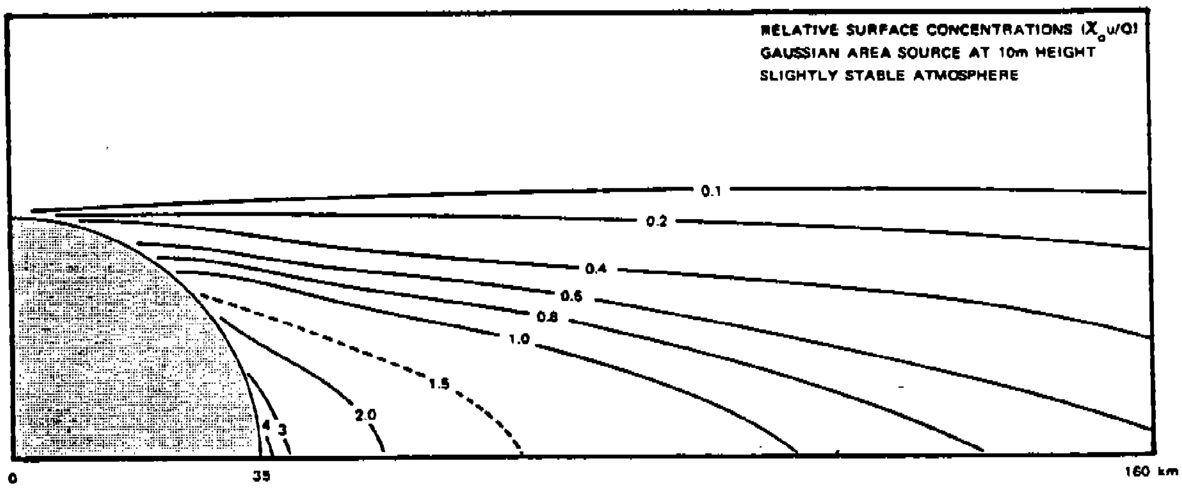


FIGURE 5-1. Normalized concentrations computed with a Gaussian dispersion model (taken from Ludwig and Kealoha, 1975).

The IDs of the other source types associated with regional-scale stations (see Table 4-2, Page 34) were determined via solutions to the Gaussian equation; typical source configurations and emission rates assumed are shown in Table 5-1. The ID calculations were based on a 3-hour average concentration at the monitoring site. A 3-hour half-life for SO_2 was assumed for all source types, except the individual home where a value of infinity was assumed. A reduction factor of 0.51 was utilized to convert the quasi-instantaneous concentration estimates to 3-hour averaging times as suggested by Turner (1974). The IDs of the various sized towns shown in Table 4-2 (Page 34) were determined by assuming that the concentration varied as the inverse of the square of the distance from the source (town) to the monitoring site.

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* See Section 5.3 for discussion of SO_2 decay characteristics.

TABLE 5-1

Configurations and Emissions for Typical Source Types Assumed in Determining Interference Distances for Regional-Scale Stations

Source Type	Characteristic Emission Period	Fuel Rate S Content (%)	Source Configuration	Emission Rate (g/sec)	Meteorology		Effective Ht. (m)
					Wind Speed	Stability Class	
Power Plant (400 MW)	365 days/yr	280×10^6 gal #6 oil @ 1% S	Point, Uniform Wind over 22.5° Sector	575	5 m/sec	D	300
Industrial Space Heat (500 T SO_2/yr)	Winter Quarter (Dec, Jan, Feb)	14×10^6 gal #6 oil @ 0.5% S	Point	58	5 m/sec	D	200
Small Town (25,000 pop., 6000 homes)	Winter Quarter (Dec, Jan, Feb)	10^3 gal/home #2 oil @ 0.2% S	Area Source 4 mi^2	10	1 m/sec	D	0
Individual Home	Winter Quarter (Dec, Jan, Feb)	10^3 gal #2 oil @ 0.2% S	Point	.0016	1 m/sec	F	0

During this phase of the study, we concluded that a major urban area, in an ID sense, may be considered as having a population of about 2×10^5 or more. This contention was based on the observation that the ID varied more closely with emission intensity rather than with total emissions; large cities emit more SO_2 than small cities, but it is emitted over a larger area. For example, the ID for a 25×10^3 population town was 15 km (Table 4-2) versus an ID of 30 km for a 1×10^6 population city; the 2×10^5 figure seemed an appropriate cut-off point to separate the large urban areas from smaller towns.

Analogous to the IDs for regional-scale stations is the concept of point, minor, and source IDs (PSID, MSID, and SID, respectively), as presented in Table 4-4 (see Page 44). These values were obtained by considering an undue influence level of $10\ \mu g/m^3$ (instead of $2.6\ \mu g/m^3$), which was the cleanest rural SO_2 background level observed. We felt that using this higher undue influence level was justified since the associated ID values are meant to apply in urban and suburban areas where existing SO_2 levels are much higher than in rural areas where regional-scale station IDs apply. Table 5-2 shows how the IDs of Table 4-4 were obtained. In developing the concentrations shown, zero effective height, a wind speed of 1 m/sec and stability class D were assumed; this would tend to produce a maximum impact at the site to provide a modest safety factor. The diffusion coefficients used in the calculations were those suggested by Bowne (1973) for rural, suburban, and urban areas. Large point sources were considered as those using 10^6 gal/yr of fuel oil. Minor sources used 10^3 gallons in rural areas (home), 10^4 gallons in suburban areas (small office building) and 10^5 gallons in urban areas (large office building). All fuel was burned during the winter quarter of the year. The concentrations as shown in Table 5-2 are unadjusted--that is, the concentrations have not been modified to account for effects due to decay and averaging time; the actual 3-hr mean concentrations were estimated by multiplying the given concentrations by an appropriate half-life factor (considering corresponding travel time) and the correction factor of 0.51 to account for additional dilution due to wind direction variability. Multiplying the circled numbers in Table 5-2 by these factors will result in an actual concentration estimate of $10\ \mu g/m^3$

Downwind distances associated with these concentrations that are shown in Table 5-2 are the IDs of Table 4-4.

TABLE 5-2

Rationale for PSIDs and MSIDs of Table 4-4 (see Page 44)

Development Intensity	Unadjusted Concentration (μg/m³)											
	Urban				Suburban				Rural			
Downward Distance (m) \ Fuel Use (gal/yr)	10^3*	10^4	10^5	10^6†	10^3	10^4	10^5	10^6	10^3	10^4	10^5	10^6
10	5.1	51	510	---	15.9	159	---	---	84.9	849	---	---
30	3.4	34	340	---	9.8	98	980	---	52.5	525	---	---
100	0.9	9	90	900	3.07	30.7	307	---	11.3	113	---	---
300	0.23	2.3	23	230	.68	6.8	68	680	1.6	16	160	---
600	.078	.78	7.8	78	.26	2.6	26	260	.5	5.0	50	500
1000	.034	.34	3.4	34	.117	1.17	11.7	117	.20	2.0	20	200
2000	.011	.11	1.1	11	.04	.4	4.0	40	.073	.73	7.3	73
3000	.006	.06	.58	5.8	.021	.213	2.13	21.3	.038	.38	3.8	38

* Individual Home

† Large Point Source

A 10° plume sector roughly corresponds to ± 1σ around the centerline of the plume. This sector width is suggested as a guide for determining those upwind sources that may unduly influence the measurements at the site. The schematic shown in Figure 5-2 illustrates the rationale for this criterion. For neighborhood-scale stations, the sector sizes were increased to 20° for the very nearby point sources.

5.2 METEOROLOGICAL PROCESSES PERTINENT TO SITE LOCATION REFINEMENT AND INLET PLACEMENT

Wind direction establishes the general transport direction and determines which sector of the area surrounding the source will receive the pollutant.

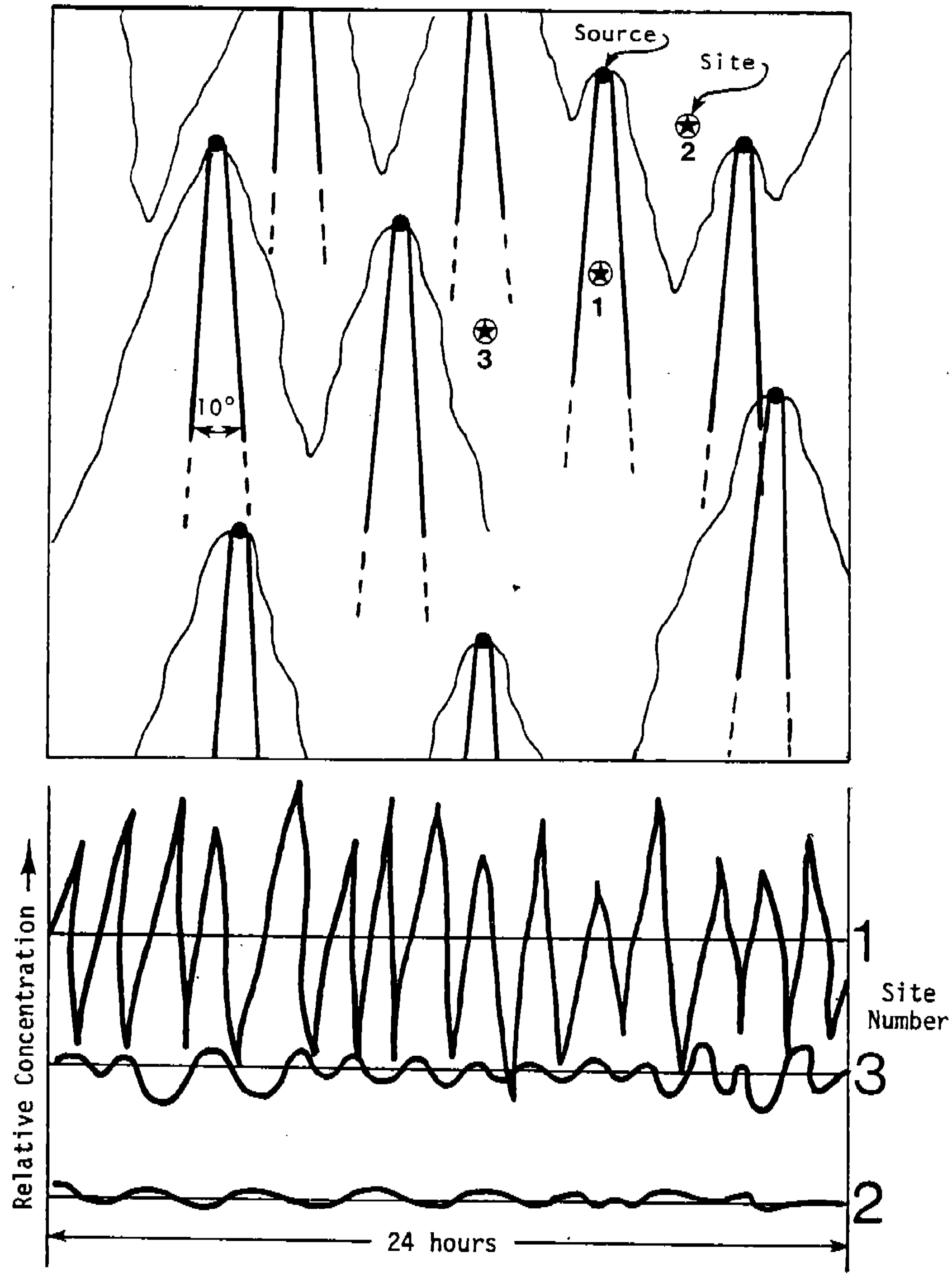


FIGURE 5-2. Schematic illustrating undue influence of nearby sources on measurements at three sampling sites: (1) within 10° plume sector; (2) at a minimum impact point within area; and (3) at a point beyond the MSID but within zone of concentration characteristic of the area as a whole.

The location of impact points within the sector are determined by the trajectory of the polluted air stream or parcel. The trajectory is only rarely a straight line--the parcel being subject to effects of obstructions that can change a given direction to another. These obstructions include mountains, valleys, buildings, and other parcels or masses of air. Even in the absence of physical obstructions, the wind varies in space and time due to thermal effects, shear effects, and turbulence advected from upwind (e.g., Fig. 6, Anderson, 1971).

The parcel may also be deformed; being a fluid, the air parcel will be subject to changes in shape and separation. However, from mass continuity considerations, there must also be corresponding changes in air flow. For example, parcels passing between two obstructions (viz., two buildings) or over a mountain will be squeezed horizontally (transverse) and vertically, respectively. In either situation, stretching of the parcel longitudinally will take place to compensate, resulting in a faster air flow. The reverse will occur for parcels moving across a valley (vertical stretching and longitudinal squeezing) (see Fig. 5-3). However, from mass continuity considerations, the concentration of the pollutant within the parcel must remain essentially the <u>same</u> throughout the deformation process.

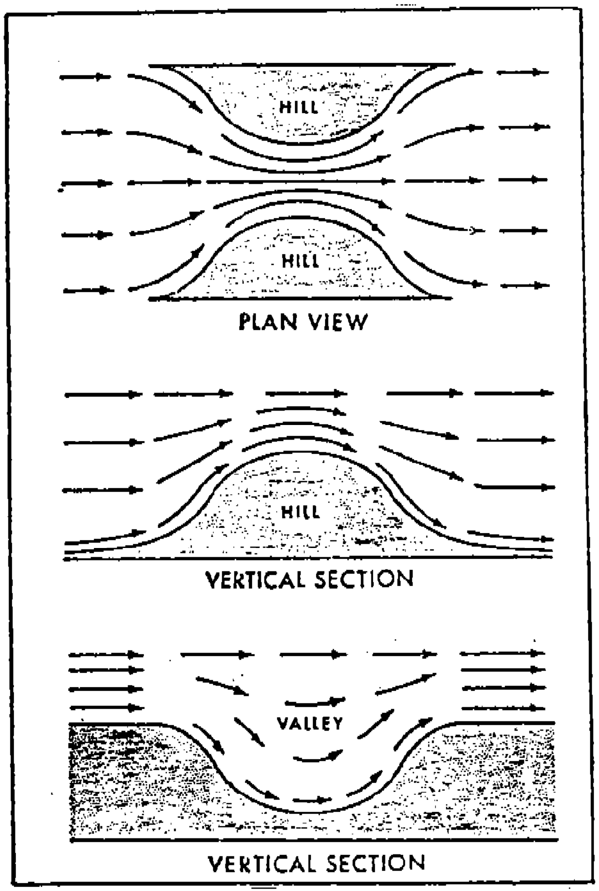


FIGURE 5-3. Topography effects on wind. Length of arrow is proportional to the wind speed.

In illustrating the concepts of wind speed and direction, and deformation, we have assumed that the pollutant remains contained within the parcel as the parcel proceeds downwind. This is not actually the case because turbulent mixing and diffusion processes are constantly at work dispersing the pollutant from the initial parcel to adjacent ones as the pollutant plume moves downwind. [Note in this regard, a point apparently missed in some of the papers reviewed that no physical mechanism exists in the atmosphere, including deformation, which can reverse the process and "unmix" the atmosphere to create higher concentrations of SO_2. Therefore, turbulence in the atmosphere can only lead to dilution or dispersion of a polluted air mass that it affects; "cavity" flows cannot accumulate pollutant--they can only partically contain it; nor can "channeling", i.e., the squeezing of streamlines, squeeze together the pollutant and increase its concentration. Indeed, no flow nor even a stagnant air mass can contain a higher pollutant concentration than that of its most intense inlet.] The rate of diffusion is a function of atmospheric stability, which is associated with varying degress of thermal or convective turbulence and the degree and nature of the roughness of the surface over which the parcels are transported, which is associated with varying degrees of mechanical turbulence.

Mechanical turbulence is produced when air moves over a rough surface, which tends to interrupt an otherwise smooth air flow. Air swirling about buildings, rough ground, and clumps of irregular sized vegetation are examples of mechanical turbulence. The degree of mechanical turbulence is directly proportional to the wind speed.

5.2.1 Effects of Natural Topography: Wakes, Channeling, and Turbulence

The transport and diffusion of a pollutant plume is complicated by the effects of natural terrain features on the flow of air in which the plume is transported.

It is suggested on the basis of work described by Anderson (1973), that topographic effects on the windfield are scaled by the ratio of topographic slopes to the depth of the mixing layer. That is, if the ground rises or falls a significant fraction of the mixing layer depth, the wind speed components should change a comparable fraction; for mixing depths on the order of 1000 ft, 100-ft elevations would usually be significant. Topographic features considerably larger than this can produce even more dramatic changes in the flow field. For example, wind flowing towards a very steep hill face is merely guided by the topography, but wind blowing off the top of a similar face will typically break up into severe turbulence and may even form a "cavity wake" as shown in Figure 5-4. (For a good review of the basic mechanism that causes wakes and wake cavities, the reader is referred to Halitsky, 1962.).

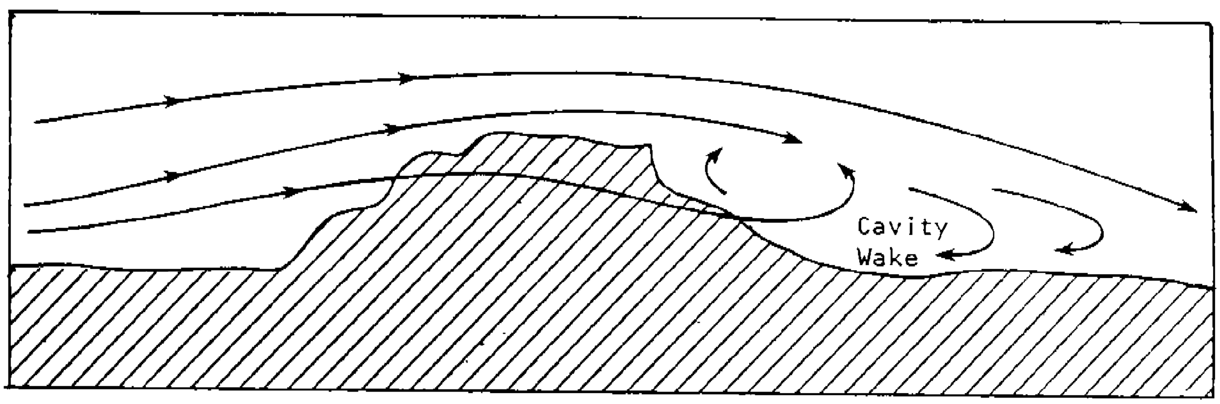


FIGURE 5-4. Assymmetry of flow approaching and leaving steep topography.

If topographic slopes exceed 10 percent, much increased turbulence can be expected with downslope winds. If topographic slopes exceed 20 percent, cavity flows are quite possible.

Inasmuch as the air entering a cavity may turn over many times before leaving, the cavity tends to average the concentration from the pollution sources that feed it. If the pollutant enters from the flow passing the obstacle, it may be thought of as continuously "sampling" the passing air, mixing it up, and passing it on much delayed. Thus, the cavity averages on both time (due to the delay) and space (due to its size) scales. The cavity cannot "collect" pollutant because it also "collects" the air which carries the pollutant, each in direct ratio to its concentration.

When the general wind direction is oblique to a ridge-valley axis, the channeling of the wind often occurs as shown in Figure 5-5. The surface wind speed in the valley is usually diminished because of friction (Flemming, 1967) If the valley wall is bluff, wake cavities (mechanical turbulence) on the lee side of the upwind wall may be produced. Wind blowing perpendicular to the valley axis will not be significantly channeled, but surface speeds can be considerably diminished (frictional drag and vertical stretching) and the probability and size of wake cavities will increase.

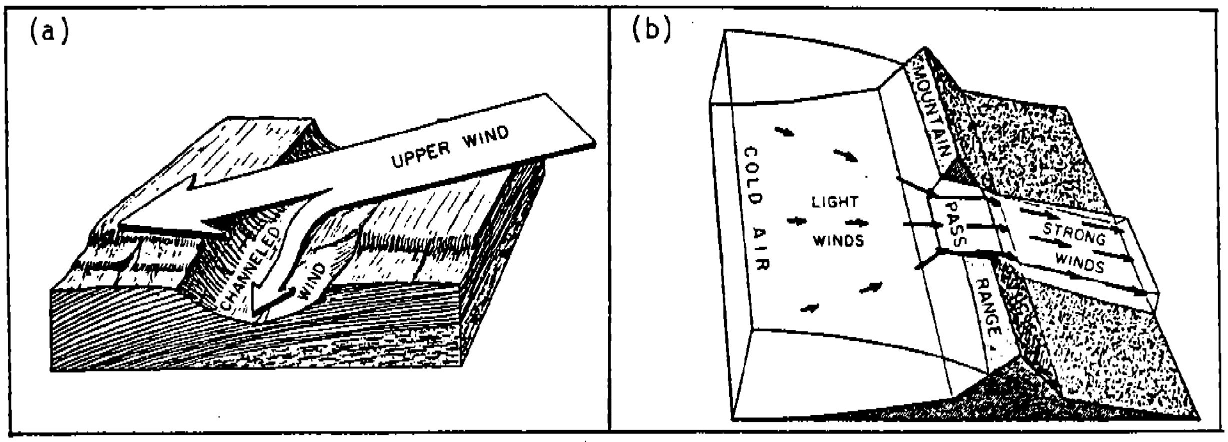


FIGURE 5-5. Distortions of the wind flow by topographic obstacles.
(a) Channeling of the wind by a valley, and
(b) The effect of a mountain pass on the wind flow.
(Taken from Slade, 1968.)

At night under clear skies and light winds, the air adjacent to the ground along the valley floor and slope are cooled through radiational cooling. As this cooling progresses, a density differential between air at the same elevation (relative to a horizontal plane) develops and results in a flow of air down the slope toward the valley floor. This flow is called a slope or drainage wind. The same mechanism also causes a flow of air downhill along the valley axis (valley wind). In the daytime under light wind conditions, the drainage flow mechanism is reversed and causes upslope and upvalley flows. Downslope and upslope air flows can be complicated in complex valley systems where several valleys merge at various angles or where slopes vary. Also, the differential heating of valley slopes can further complicate the already complex flow pattern.

The only significant modification of winds and turbulence (and hence SO_2 concentrations) due to irregular topography is that it increases mechanical turbulence. The scales of this turbulence depend on the strength of the wind and the size and size distribution of the individual features. If the features are large, wake cavities may form; otherwise the turbulence elements are of small scale. If the area is generally level, flows produced by drainage and valley flow mechanisms will be insignificant. In general, smooth hills alter the flow least. Under unstable conditions, air parcels tend to move over obstacles, while under stable conditions, air parcels tend to move around obstacles. In strong winds, cavity wakes can form on the lee side of large bluff hills.

Trees can obstruct an otherwise smooth wind flow and increase mechanical turbulence. Dense clumps of large trees can have the same effect on wind flow as a small, bluff hill and produce wake cavities. Similarly, wake cavities may exist on the windward side of a forest clearing. Below a forest canopy, wind speeds may be very low and diurnal temperature variations tempered. Irregularly spaced trees or small clumps of trees of varying height, lines of trees, and low vegetation will have the same effect as rough topography and increase mechanical turbulence.

5.2.1.1 Effects of Above Considerations on SO_2 Distribution

The effects of ridge-valley topography on SO_2 concentrations and patterns depend on several factors. The major factors are the time of day the pollutants are being emitted, where they are being emitted, the height of release, and the prevailing meteorology. An SO_2 plume emitted from the top of the valley wall or on an adjoining plateau may be caught up in a cavity wake (downwash) and brought down into the valley. At night, an SO_2 plume released at a high level at a high exit velocity may escape the valley and surrounding high terrain entirely. On the other hand, lower level releases may become imbedded in the drainage flow and move down the valley, or, emerge above the drainage flow upper boundary and impact (not intersect) on the valley wall or slope. Emissions from intense area sources (low-level) located in valleys and released into a very stable drainage flow or a deep, intense inversion layer will be severely restricted both horizontally and vertically.

Unless large obstacles are present, moderately rough natural topography will decrease the pollutant concentration by increasing mixing because of mechanical turbulence; therefore, the concentration levels measured will be less sensitive to the location of the site or placement of the instrument inlet. Wake cavities formed on the lee sides of the largest bluff obstacles may cause the downwash of a passing plume.

The effects on SO_2 plume behavior induced by vegetation are similar to those caused by irregular, rough terrain. However, an individual SO_2 plume passing over a clearing in a forest at a low level (viz., a low-level release from a nearby source) may be downwashed to the ground via a wake cavity formed on the windward side of the clearing.

5.2.2 Effects of Urbanization: General

The effect of urbanization on meteorological elements is described very well by Pooler (1963) and summarized by Peterson (1969). In their work, they discuss urban effects on the horizontal and vertical distributions of temperature, humidity, visibility, radiation, wind, and precipitation. The urban "heat island" phenomena has been well documented in studies by DeMarrais (1961), Mitchell (1961), Bornstein (1968), and Oke (1975). In these studies, characteristic vertical and horizontal variations, wind flows, and stability changes are discussed and compared to adjacent rural areas. Oke (1973) related city size and urban heat island intensity. Hutcheon, et al. (1967) show that even small cities can produce urban heat islands. From these studies, the effects of the various meteorological elements relevant to SO_2 behavior (and, therefore, monitoring site exposure criteria) are summarized here.

Nighttime temperatures in cities are higher than those observed over adjacent rural areas. Generally, the larger the city and more intense the nocturnal inversion, the larger the temperature differential between the urban core area and the outlying rural area (as great as 20°F). Heat island intensity has been shown to be related to the logarithm of population according to a study by Oke (1973) for a group of North American cities. Daytime temperature differentials are generally much less apparent than at night and occasionally are reversed.

Higher surface temperatures in urban areas reduce atmospheric stability. In fact, in large cities surface-based inversions are quite rare. Decreased stability, increased mixing depths, and increased mechanical turbulence, due to the rough urban topography, all tend to enhance the mixing and dispersion of pollutants.

Frictional drag and the urban heat island effect modify the urban wind direction. During the daytime, particularly under unstable conditions, wind directions over the cities and rural areas are reasonably homogeneous. However, at night the relatively warmer air of the city rises, causing low-level convergence and an inflow of air toward the urban center as observed by Pooler (1963). The inflow is strongest at night when the urban heat island is well developed. Of course, the magnitude of the effect is dependent on city size. In many cases, this inflow toward the urban center is observed whenever regional winds are weak. Often in extreme conditions, an outflow of urban air aloft is observed and results in a closed circulation.

5.2.2.1 Building-Induced Turbulence and Wakes

The material in this section is presented as support documentation for the criteria contained mainly in Tables 4-3 (see Page 39) and 4-5 (see Page 45).

The major area of concern here is the representativeness of urban monitoring sites in view of the complication in the wind and turbulence fields, particularly in the daytime, due to urban structures. Even the idealized situation of a single building is quite complex as shown in Figure 5-6. In cities, complex street canyon flows and cavity wakes on the lee side of buildings dominate the flow pattern. Since high SO_2 concentrations are often observed in urban areas (and is the rule in the north), a major effort was made to reflect in the urban site selection guidelines an accounting of such complex urban flow characteristics. In addressing the phenomena, some studies treating the problem by two basic techniques were reviewed--mathematical modeling (Hotchkiss and Harlow, 1973) and physical modeling (Halitsky, 1962). Neither technique provided comprehensive quantitative answers. However, each provided some insight into the problem. In general, features of complex urban flows are difficult to generalize via both mathematical and physical modeling because the dominant flow features near buildings cannot be represented as turbulence or as "potential flow" (i.e., a solution to the potential function equation).

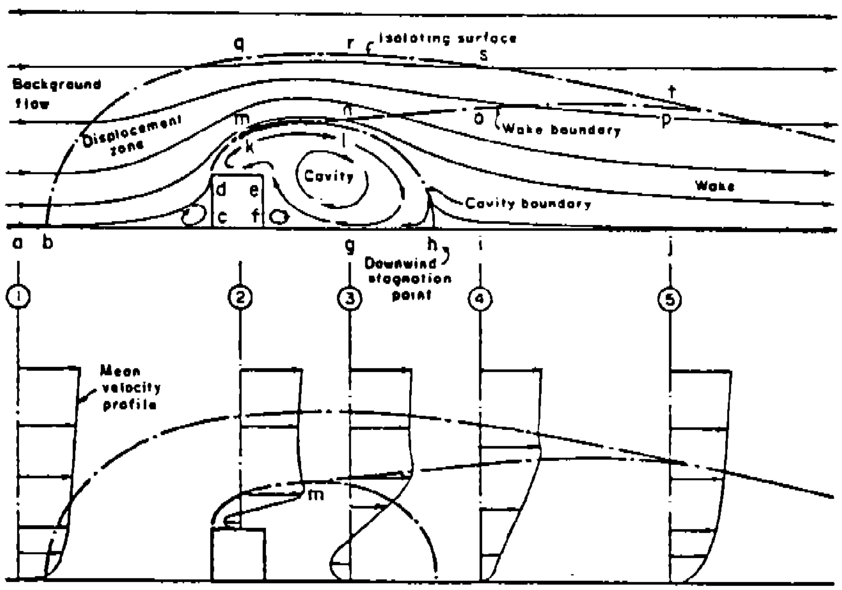


FIGURE 5-6. General arrangement of flow zones near a sharp-edged building (taken from Slade, 1968).

Cavity flows, as shown in Figure 5-7, and wake flows, as shown in Figure 5-8, contain features as large or larger than the obstacles creating them and yet are in no way random. They may, however, be embedded in random turbulence, and are, in general, dependent on very fine scale features of the flow such as the precise angle of incidence and the smoothness and precise shapes of the surface contours. Thus, numerical models which only introduce turbulence of a fixed intensity in the incident flow cannot reproduce the effect of the incident flow containing a regular train of eddies as large as the building.

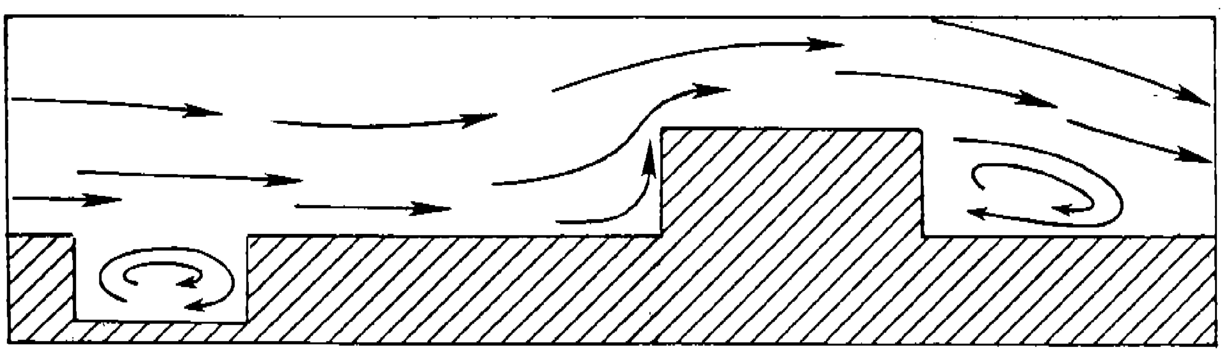


FIGURE 5-7. Cavity flows.

If models contain upstream structures to generate such eddies, they still cannot represent the formation or release rate of such eddies which depend on microscale surface details of the building.

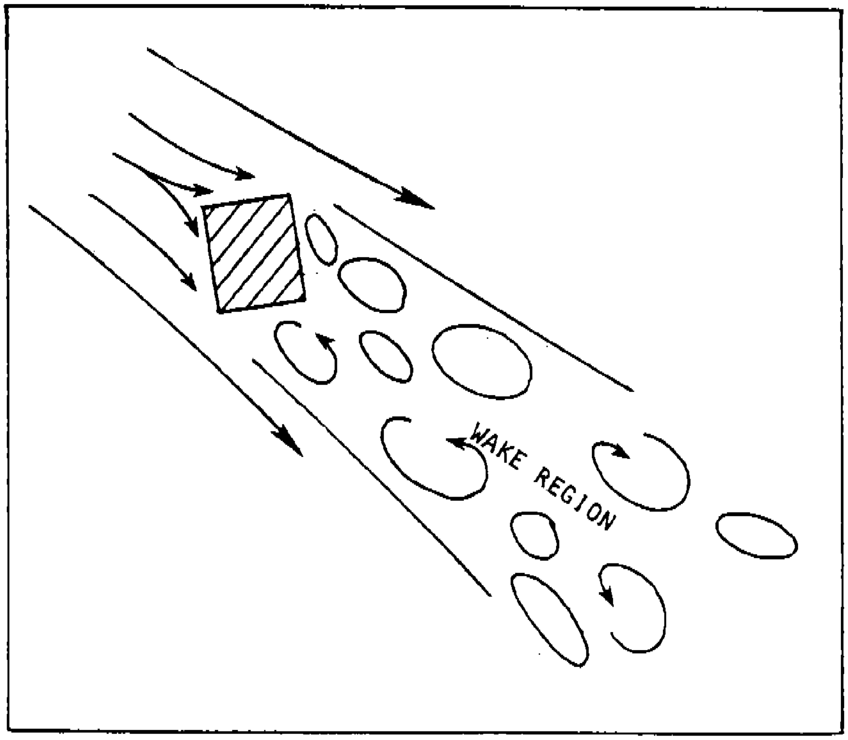


FIGURE 5-8. Wake region in flow past bluff obstacle (viewed from above).

A virtue shared by both numerical and physical modeling is that gross, qualitative features are quickly, cheaply, and/or distinctly shown, and the existence of large, coherent disturbances and their general nature can often be determined by such modeling programs. However, their location, size, typical residence time when trapped, or the pollutant concentrations resulting from plume interaction cannot usually be determined. For example, the wind tunnel studies described by Halitsky (1962), show that in some cases highest pollution flux is against the mean wind; whereas on superficially comparable building parts, no such reverse flow is evidenced. On other building roofs, pollutant transport is transverse to the mean wind. All of the observations might lead to conclusions that might be invalidated by slight changes in incident wind direction, or variability. The experiment does legitimately warn the selector of monitoring sites that one cannot easily or casually choose a site and be sure that it will be upwind (statistically) of a nearby source in a complex structural environment. However, in a later study, Drivas and Shair (1974) showed that a reverse circulation in the wake downwind of a building generally exists and that tracer experiments indicated that the extent of the recirculation back onto the roof was, in general, systematically confined to less than one-half the width of the building from the downwind edge.

5.2.3 Relevance of Above Considerations on Siting Criteria

The urban modifications to the regional meteorology that have a major impact on SO_2 concentrations and patterns are the air inflow characteristics under stable conditions when regional winds are weak, particularly at night, and the effects of wake cavities on the lee sides of buildings under stronger regional wind conditions.

When a heat island circulation exists, individual pollutant plumes may tend to converge toward the center of the city where they will rise, then return aloft to the periphery of the urban area and return again, completing the circulation (convergence at low levels, divergence aloft (see Figure 5-9). With a large number of SO_2 plumes tending to converge toward one central point and the return from aloft of already polluted air, a pollutant maximum may be located near the urban center. From heat island circulation dynamics, Chandler (1968) deduced that urban-rural pollution gradients would be very sharp with the strongest gradients on the lee side of the city. Ball (1969) observed that pollutant peaks roughly coincided with the thermal maximum of New York City's heat island and that the thermal pattern shifted and elongated in response to the regional wind flow.

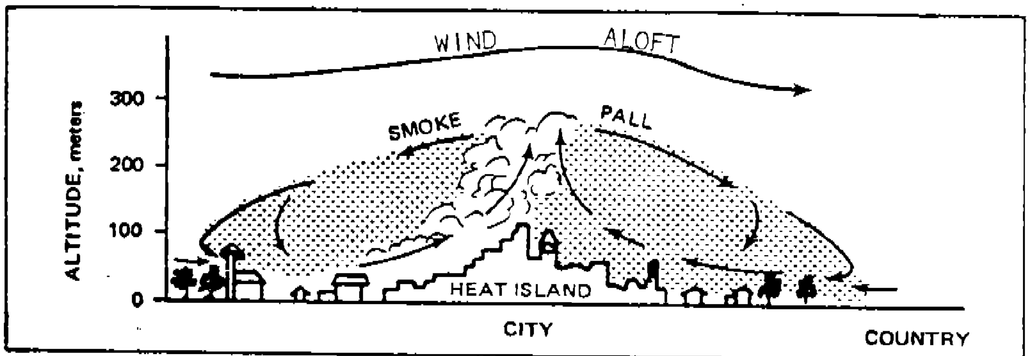


FIGURE 5-9. Urban circulation and dispersion before sunrise.

Under stronger wind speed conditions, particularly during the day, heat island circulations break down and lose their identity. Complex building wake patterns then distort the wind flow resulting in a very turbulent urban atmosphere, and become a major factor in influencing SO_2 concentrations and distributions. Figures 5-10 and 5-11 show mathematical representations of the effects of building wakes and cavity flows on pollutant distribution. In a large urban area, these complex flows would typically produce an averaging effect in both the horizontal and vertical. This statement is suppprted by Pelletier (1963) who measured SO_2 distributions in Paris; at specific locations he found no appreciable difference in 24-hour mean SO_2 concentrations measured at 13 m and 53 m above the ground. The same conclusions were reached by Clifton, et al. (1959) in a Sheffield, England study, particularly for locations not too near the upwind edge of the city (to allow sufficient time and distance for the wake/cavity-induced averaging effect to take place). Simon (1969) described a similar situation, in considerable detail, in his discussion of New York City's meteorology program. From the above considerations, what seems to emerge regarding the vertical distribution of SO_2 in urban areas is illustrated in Figure 5-12 and described as follows:

- A parcel of air entering the city is characterized by very low concentrations uniformly distributed in the vertical. At it passes through the suburbs, it picks up contributions from relatively small sources at low-to-moderate heights. As it passed through the central business district (CBD), very large amounts of SO_2 are picked up; but because of plume reflection and the mixing/averaging effect produced by building wakes, the SO_2 distribution is substantially uniform up to at least the mean building height. However, it is likely that a maximum concentration level may be observed above the mean building height near the mean effective height of the stronger sources which are emitted at higher levels. This statement is substantiated by Simon (1969, Fig.6). As the air leaves the city, the upper profile "fills in" due to the upward dispersion from lower levels. This effect plus horizontal dispersion continues until a vertically uniform, general low-to-moderate concentration level results just downwind of the city.

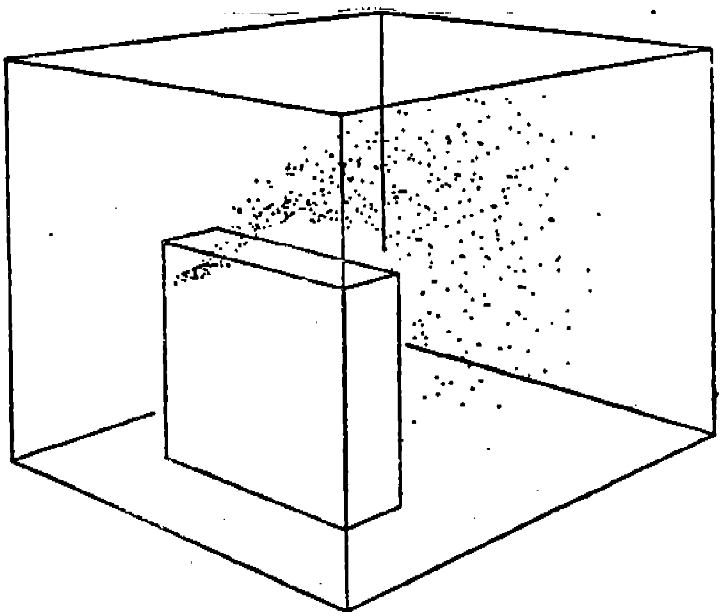


FIGURE 5-10.

The dispersal of a narrow plume passing over a single building. Recirculation in wake region is clearly evident. (Taken from Hotchkiss and Harlow, 1973.)

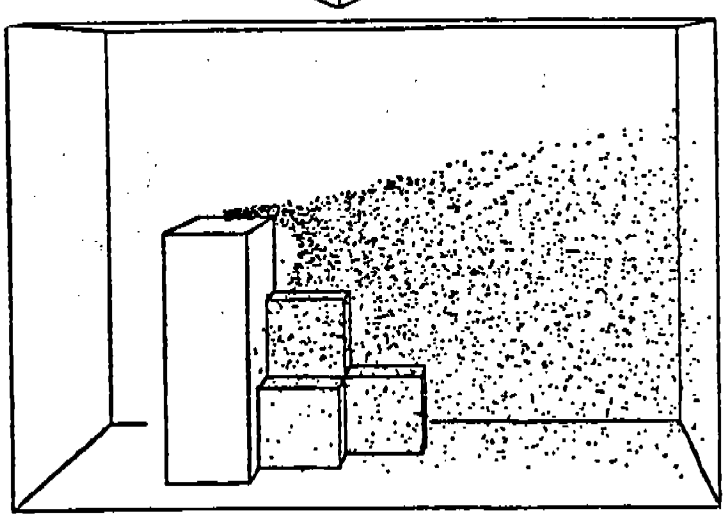


Figure 5-11.

The dispersal of pollutant from a flush vent on the top of a complex building structure. (Taken from Hotchkiss and Harlow, 1973.)

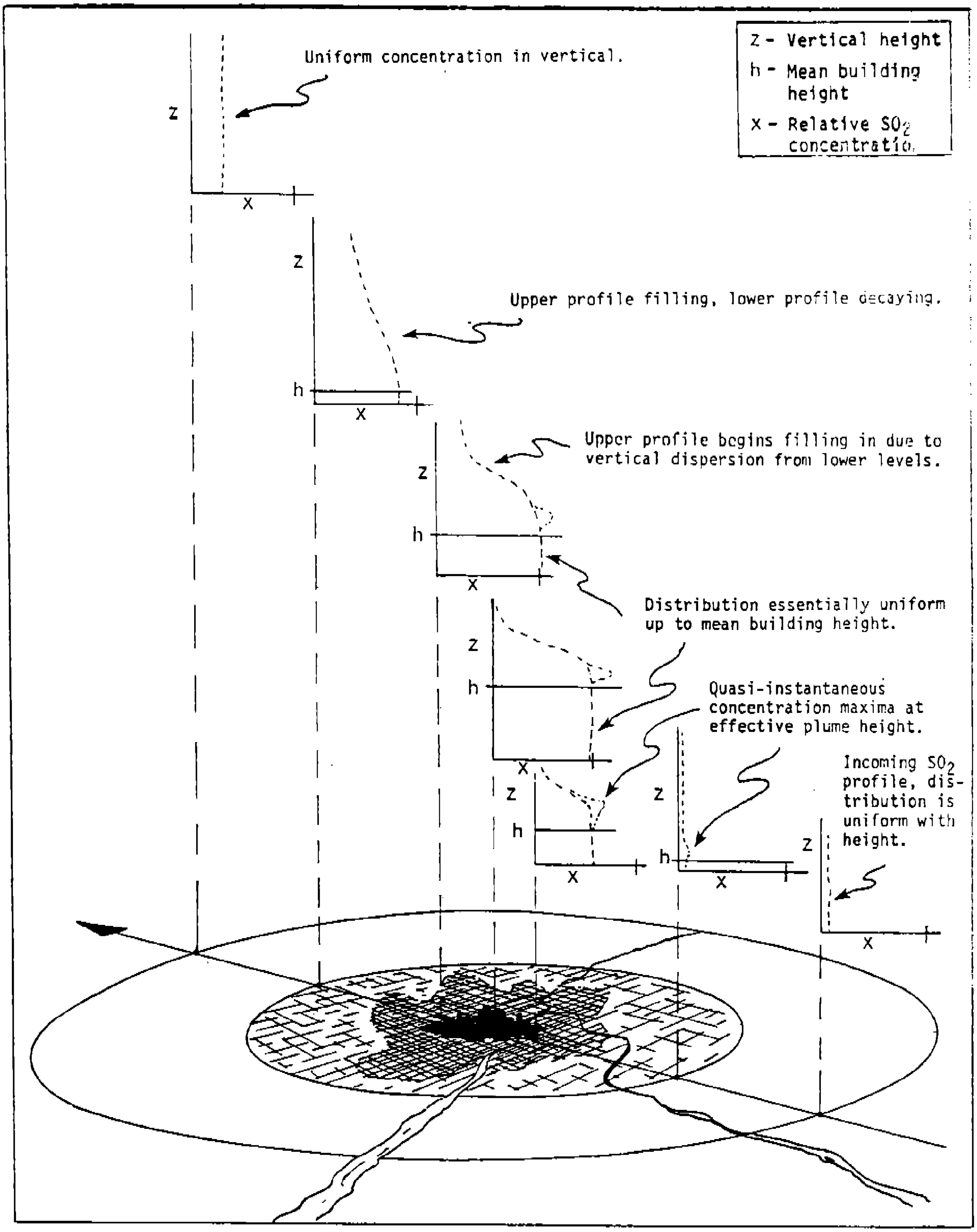


FIGURE 5-12. Schematic illustration of vertical distribution of SO_2 within a vertical column of air passing through an urban area.

From the above discussions, the following conclusions can be drawn:

- Mixing produced by mechanical turbulence and wake effects of larger obstacles over moderately rough, natural terrain averages the pollutant over space which lessens the concern of exact site location and inlet placement in rural areas.

- Micro-scale urban features substantially increase mixing and promote uniformity of pollutant levels from mid and far distant sources. This mixing between source and monitoring site, reduces the monitoring site selection problem to the consideration of only near sources (less than the interference distance).

- A single building wake can mix, over its volume, pollutant from a source that enters it. Thus, standard analyses compute a "virtual point source" upwind of a building if the building wake is thought to catch its own plume.

- The uniform mixing principle is not absolute and cavity flows often build, get swept away, and reform, leading to large "puff" type releases.

- Except for near the windward edge of a city, a vertically uniform SO_2 distribution up to at least the mean building height over the area of interest in the city can be assumed. The choosing of 0.8 $\bar{H}$ (or lower) for inlet location above the ground (see Table 4-3, Page 39; and Table 4-5, Page 45) is somewhat arbitrary, but was meant to insure that the instrument (or inlet) would be placed at a point in the vertical where the measured levels would approximate those existing near the breathing zone--5-6 ft above the ground.

- If pollutant release is known to be well within a cavity (e.g., emissions from a vehicle in a deep, street canyon) averaging will not be complete and concentration fluctuations and gradients are apt to be found within the flow. Minimum velocities and maximum concentrations should be found near the ground on the leeward side of the obstacle. This is the justification for avoiding trailer locations just downwind of buildings with large stacks (see Table 4-5). This situation is precluded, however, if the interference distance criteria are satisfied.

- Pollutants from sources located downwind of a building may be emitted into the wake cavity behind the building. The reverse flow of the wake may advect pollutants up to the roof of the building to at least one-half of the width of the building from the downwind edge. This observation is the rationale for recommending that inlet placement locations be on the windward side of the building (see Table 4-5). It also justifies the recommendation of not having SO_2 sources on the roof of the building chosen for the monitoring site or inlet location.

- Emergency episode stations should be located in the very heart of the maximum SO_2 emission density zone of an urban area; during air stagnations wind speeds are low and directions are variable so the maximum concentration should occur where the emission density is a maximum. However, even in this case, caution should be exercised in locating monitors. SO_2 emissions from high stacks (which are often the largest sources) may not reach the ground (if at all) until several miles away during a low wind-speed/stable situation. Appropriate site locations can best be found by using gridded emission inventory data with most of the weight being given to the area source fraction of the inventory.

- The heat island mechanism may produce maximum concentrations near the wind inflow convergence point which may be located near the center of maximum SO_2 emission zone of the city. This justifies considering the emergency episode station as an alternative site for measuring the 3-hour peak concentration.

5.3 MISCELLANEOUS CONSIDERATIONS

In this section, additional justification and rationale regarding certain siting criteria, modeling approaches and miscellaneous considerations along with support documentation is presented.

5.3.1 Temperature

The temperature at a point has little direct effect on the concentration of SO_2. Only temperature gradients, mainly in the vertical, have a major influence. However, temperature may influence the rate of emission of SO_2; for example, the amount of fuel burned for space heating is directly proportional to heating degree days, a number which is equal to the average temperature for the day minus 65°F. Turner (1968) and Roberts, et al. (1970) related SO_2 emission rate response to changes in temperature on an hourly (diurnal variation) as well as a daily mean basis. Power plant load (and SO_2 emissions) may vary seasonally and diurnally. In the northern part of the United States, power plant emission maxima occur in both summer and winter in response to power demand to run air conditioners (related to cooling degree days), and in response to demand to run electric and oil heating systems (related to heating degree days) (Federal Power Commission, 1971).

5.3.2 Chemical-Physical Interactions

SO_2, being soluble in water, interacts both chemically and physically with atmospheric moisture. SO_2 is also photochemically and catalytically reactive with other atmospheric constituents. The reaction kinetics of such interactions are very complex, all aspects of which are not yet fully understood. Some of the end products of atmospheric interactions involving SO_2 are sulfur trioxide, sulfuric acid, and sulfates. SO_2 also interacts with ground, vegetative, and water surfaces. Since it is beyond the scope of this report to present a detailed discussion of this topic, only a brief summary of the more pertinent aspects is presented.

5.3.2.1 Reactions of SO_2 With Atmospheric Liquid Water

Precipitation scavenging consists of three basic components as described by Slade (1968):

1) transport of the SO_2 to the scavenging site,

2) in-cloud scavenging by precipitation and cloud elements (rainout), and

3) below-cloud scavenging by falling raindrops (washout).

The rate of scavenging of SO_2 is based on the molecular diffusion of SO_2 to the droplets in accordance with the vapor pressures and solubility of SO_2. Laboratory tests by Bracewell and Gall (1967) indicated that the occurrence of H_2SO_4 in urban fogs could be accounted for by the catalytic oxidation of SO_2 dissolved in fog droplets in the presence of certain metallic ions.

5.3.2.2 Catalytic and Photochemical Oxidation Reactions

SO_2 may be catalytically oxidized to SO_3 in the presence of oxides of nitrogen. The SO_3 then readily converts basic oxides to sulfates (NAPCA,1970). Liberti and Devitofranesco (1967) reported that SO_2 may be catalytically oxidized to sulfate after being adsorbed by suspended particles. In a report to the U.S. Senate, the National Academy of Sciences (NAS, 1975) reported that SO_2 oxidation rates (to sulfates) varies from 0.17 percent/hour to 50 percent/hour, depending on the relative humidity and the presence and relative concentrations of other pollutants. The rate is typically more rapid in urban air. Urone, et al. (1968) reported that SO_2 can be photo-oxidized to H_2SO_4 aerosol in the presence of water vapor and at a faster rate when hydrocarbons and nitrogen dioxide are present. In the same NAS report cited above, it was estimated that in the northeastern United States, roughly one-third of SO_2 emissions are returned to the earth as sulfates.

5.3.2.3 Reactions With Ground and Water Surfaces

In a study by Spedding (1972), the ocean was found to be a major sink for SO_2. He concluded that SO_2 deposition velocities (V_g = deposition/surface area/time of exposure/atmospheric concentration) were proportional to the flow rate of the SO_2-air mixture. Under calm conditions, he estimated a value of V_g of 0.28 cm/sec. Owers and Powell (1974) estimated an SO_2 deposition velocity of 0.8 cm/sec over land and water surfaces. Similar values were found by Shepard (1974) for grass in summer but were much less in the autumn (0.3

cm/sec). Over water he found that V_g was proportional to windspeed. Garland, et al. (1974) reported a deposition velocity of 0.55 cm/sec onto short grass. Individual values varied widely and were independent of the weather. He also estimated that 25 percent of the SO_2 emitted within Great Britain was deposited by dry deposition.

5.3.2.4 Residence Times and Half-Life

Residence times and half-lives of SO_2 are extremely variable because of the very complex interactions of SO_2 with other reactive pollutants, atmospheric liquid and gaseous water, surface water, land and vegetative surfaces, sunshine, and weather. Eliassen and Saltbones (1975) reported a residence time for SO_2 of about one-half day, or a decay rate of about .002 percent/sec. In their work, they considered dry deposition and oxidation to sulfates.

In general, the various oxidation/deposition rates for SO_2 as summarized above correspond to half-lives ranging from about one hour to several days. The shorter half-lives are probably characteristic of urban SO_2 where sufficient quantities of reacting pollutants exist to hasten the transformation process.

Figure 5-13 is a schematic showing SO_2 transport, diffusion, and various removal processes.

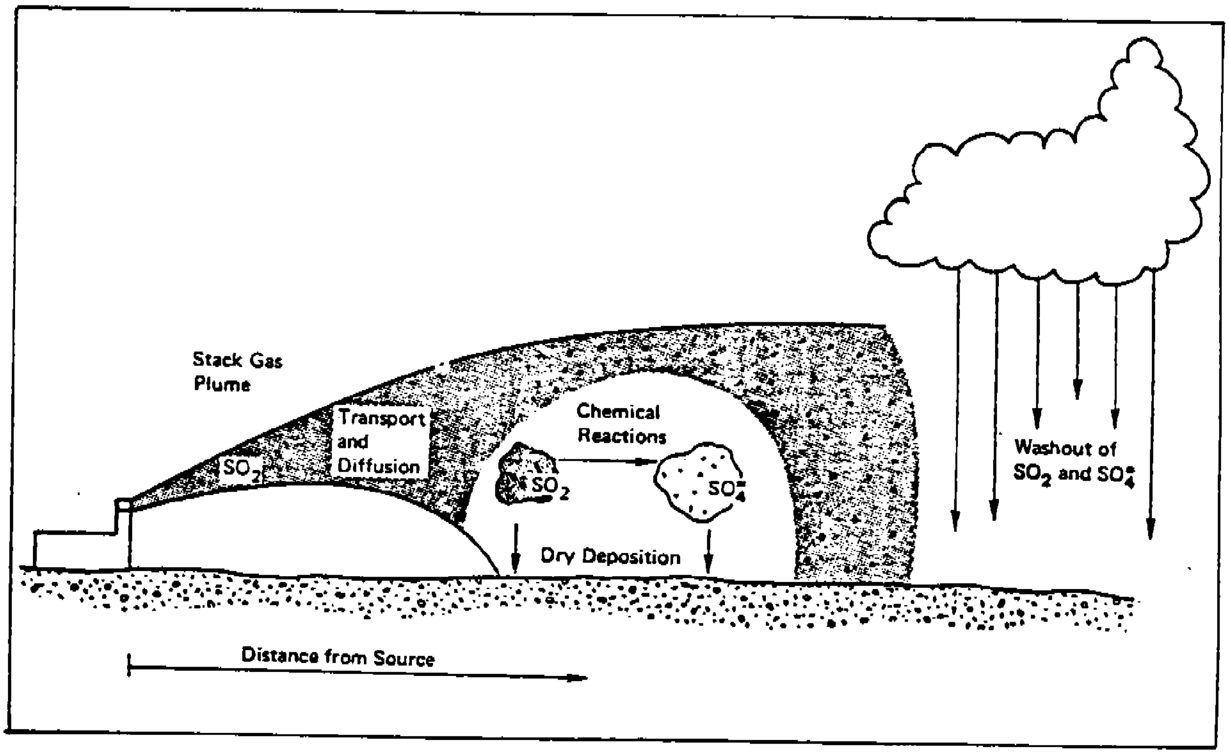


FIGURE 5-13. Processes involved in the relationship of sulfur oxide emissions to air quality (taken from NAS, 1975).

5.3.2.5 SO_2 Reactivity and Monitoring Device Inlet Tubes

Because of the adsorption-desorption characteristics of SO_2, care must be taken in choosing the kinds of inlet tubes for SO_2 monitoring devices. Stainless steel, glass, and teflon have been shown (Wohlers, et al., 1967) to be nonreactive for either high flow (28.3 l/min) or low flow (1.4 l/min) sampling through 30.5 m lengths (1.27 cm i.d.) of tubing made from such material.

5.3.3 Relevance of Above Considerations to Siting Criteria

Ambient temperature levels dictate the amount of fuel to be consumed for space heat. Since the coldest temperatures occur in winter, the prevailing wind direction for the three core winter months (December, January, and February) was considered as the "upwind" direction for determining the sources most frequently upwind of prospective monitoring sites.

The very complex problem regarding the chemical/physical interactions of SO_2 was addressed by assuming that SO_2 decays exponentially with a half-life of three hours, generally, but one hour for cities of over 10^6 population. The population figure is somewhat arbitrary, but the objective was to address the fact that the chemical conversion of SO_2 in the largest urban areas proceeds at a faster rate than in rural areas. Using an appropriate half-life value in all modeling exercises is important, particularly for assessing point sources in urban settings and in the process of determining the sizes of projected growth or population areas to be represented by either neighborhood or middle-scale stations (see Section 4.3.2). In the former, the contribution of SO_2 at the monitoring site due to the source is a function of transit time (and half-life) as well as distance; in the latter, the concentration gradient is a function of half-life. In the same section (4.3.2), the $0.5\ \mu g/m^3$ - km gradient value is arbitrary; it was considered a realistic threshold value separating steep and flat concentration gradients and was chosen via inspection of SO_2 concentration maps. Also, in the same section, the extreme concentration value span of $\pm$ 25 percent of the mean concentration over an area, for determining whether one monitoring site will represent concentrations over the area, is also arbitrary. However, this value, considered as reasonable for most purposes as given, could be adjusted to satisfy any purpose at the discretion of the site selector.

The remaining siting and inlet placement criteria of Table 4-3 (see Page 39) and Table 4-5 (see Page 45) not specifically addressed above are consistent with those found in existing guidelines (e.g., EPA, 1971, 1974b). They are recommended mainly to prevent contamination of the instrument from dust sources on the roof of the site building or to insure a proper exposure to the open ambient air stream.

6.0 REFERENCES

AEC, 1972: *Safety Guide 23, On-Site Meteorological Programs*, Atomic Energy Commission (AEC), Washington, D.C., 23.1-23.6.

Anderson, G.E., 1971: Mesoscale influences on windfields. *J. Appl. Meteor.*, *10*, 377-386.

_____, 1973: *A Mesoscale Windfield Analysis of the Los Angeles Basin*, EPA Contract No. 68-02-0223, EPA, National Environmental Research Center, Meteorological Laboratory, Research Triangle Park, N.C., 42 pp.

ASME, 1968: *Recommended Guide for the Prediction of the Dispersion of Airborne Effluents*, ASME Committee on Air Poll. Cont., United Engineering Center, New York, N.Y., 85 pp.

Ball, R.J., 1969: *Interstate Transport of Air Pollution in Southwestern Connecticut*, in-house report, Department of Health, State of Connecticut, Hartford, Connecticut, 94 pp.

_____, et al., 1972: *Air Quality Implementation Plan*, in-house report, Department of Environmental Protection, State of Connecticut, Hartford, Connecticut, 320 pp.

Bornstein, R.D., 1968: Observations of the urban heat island effect in New York City. *J. Appl. Meteor.*, *7*, 575-582.

Bowne, N.E., 1973: *Diffusion Rates*, Paper #73-130 presented at the 66th Annual Meeting of the Air Poll. Control Assoc., Chicago, Illinois, June 1973, 18 pp.

Bracewell, J.M. and D. Gall, 1967: The Catalytic Oxidation of Sulfur Dioxide in Solution at Concentrations Occurring in Fog Droplets. *Proc., Symp. Physico-Chemical Trans. of Sulfur Compounds in the Atmos. and the Formation of Acid Smogs*, Organization for Economic Cooperation and Development, Mainz, Germany, June, 1967.

Brier, G.W., 1973: *Validity of the Air Quality Display Model Calibration Procedure*, EPA-R4-73-017, Office of Research and Monitoring, EPA, Research Triangle Park, N.C., 28 pp.

_____, 1975: *Statistical Questions Relating to the Validation of Air Quality Simulation Models*, EPA 650/4-75-010, National Environmental Research Center, Meteorology, Lab., EPA, Research Triangle Park, N.C., 21 pp.

Cavender, J.H., D.S. Kircher, and A.J. Hoffman, 1973: *Nationwide Air Pollution Emission Trends, 1940-1970*, in-house report, Pub., AP-115, Office of Air and Water Prog., EPA, Research Triangle Park, N.C., 52 pp.

Chandler, T.J., 1968: The bearing of the urban temperature field upon urban pollution patterns. *Atmos. Environ.*, *2*, 619-620.

Clifton, M., D. Kerridge, W. Moulds, J. Pemberton, and J.K. Donoghue, 1959: The reliability of air pollution measurements in the rleation to the siting of instruments. *Int'l. J. Air and Water Poll.*, *2*, 188-196.

Collins, G.F., 1971: Predicting sea breeze fumigation from tall stacks at coastal stations. *Nuclear Safety*, *12*, 110-114.

DeMarrais, G.A., 1961: Vertical temperature difference observed over an urban area. *Bull. AMS*, *42*, 548-554.

DHEW, 1967: *Technical Report: New York - New Jersey Air Pollution Abatement Activity; Sulfur Compounds and Carbon Monoxide*, in-house report, Dept. Health, Education, and Welfare, DHEW, PHS, National Center for Air Pollution Control, Cincinnatti, Ohio, 59-75.

Drivas, P.J. and Shair, F.H., 1974: Probing the air flow within the wake downwind of a building by means of a tracer technique. *Atmos. Environ.*, *8*, 1165-1175.

Eliassen, A. and J. Saltbones, 1975: Decay and transformation rates of SO_2 as estimated from emission data, trajectories and measured air concentrations. *Atmos. Environ.*, *9*, 425-430.

EPA, 1971: *Guidelines: Air Quality Surveillance Networks*, in-house report, Publ. AP-98, Office of Air Programs, EPA, Research Triangle Park, N.C., 16 pp.

_____, 1973a: *Monitoring and Air Quality Trends Report, 1972*, in-house report, Publ. EPA 450/1-73-004, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, N.C., 210 pp.

_____, 1973b: *The National Air Monitoring Program: Air Quality and Emissions Trends. Annual Report, Vol. II*, in-house Report, Publ. EPA 450/1-73-0016, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, N.C., 350 pp.

_____, 1974a: *Guidelines for Air Quality Maintenance Planning and Analysis*, Vols. 1-12, Office of Air Quality Planning and Standards, Monitoring and Data Analysis Div., EPA, Research Triangle Park, N.C.

_____, 1974b: *Guidance for Air Quality Monitoring Network Design and Instrument Siting*, in-house Report, OAQPS No. 1.2-012, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, N.C., 33 pp.

_____, 1974c: *Guidelines for Air Quality Maintenance Planning and Analysis: Vol. 10, Reviewing New Stationary Sources,* EPA Contract 68-02-1094, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, N.C., 78 pp.

_____, 1974d: *Monitoring and Air Quality Trends Report, 1973,* in-house report, Publ. EPA 450/1-74-007, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, N.C., 312 pp.

_____, 1974e: *Guidelines for Air Quality Maintenance Planning and Analysis: Vol. 12, Applying Atmospheric Simulation Models to Air Quality Maintenance Areas,* in-house report, Publ. OAQPS No. 1.2-031, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, N.C., 42 pp.

Federal Power Commission, 1971: *The 1970 National Power Survey, Part 4,* U.S. Government Printing Office, Washington, D.C.

Federal Register, 1971: *Requirements for Preparation, Adoption, and Submittal of Implementation Plans, 36*(158), Saturday, August 14, 1971.

_____, 1973a: *Maintenance of National Ambient Air Quality Standards, 38*(116), Monday, June 18, 1973.

_____, 1973b: *Submission of Transportation and/or Land Use Plans, 38*(52), Tuesday, March 20, 1973.

_____, 1973c: *Use of Supplementary Control Systems and Implementation of Secondary Standards, 38*(178), Friday, September 14, 1973.

_____, 1974: *Prevention of Significant Air Quality Deterioration, 39*(235), Thursday, December 5, 1974.

Flemming, G., 1967: Concerning the effect of terrain configuration on smoke dispersal. *Atmos. Environ., 1,* 239-252.

Garland, J.A., D.H.F. Atkins, C.J. Readings, and S.J. Caughey, 1974: Deposition of gaseous sulphur dioxide to the ground. *Atmos. Environ., 8,* 75-80.

Gill, G.C., L.E. Olsson, J. Sela, and M. Suda, 1967: Accuracy of wind measurements on towers or stacks. *Bull. AMS, 48,* 665-674.

Halitsky, J., 1962: Diffusion of vented gas around buildings. *J. Air Poll. Control Assoc., 12,* 74-80.

Hawkins, J.E. and G. Nonhebel, 1955: Chimneys and the dispersal of smoke. *J. Inst. Fuel, 28,* 530-545.

Heller, A.N. and E.F. Ferrand, 1969: *The Aerometric Network of the City of New York,* in-house report, Dept. of Air Resources, The City of New York, N.Y., 25 pp.

Herrick, R.A., 1966: Recommended standard method for continuing dust fall survey (APM-1, Revision 1). *J. Air Poll. Control Assoc., 16*, 372-377.

Hewson, E.W. and G.C. Gill, 1944: Meteorological investigation in Columbia River Valley near Trail, B.C. *U.S. Bureau of Mines Bull., 453*, 23-228.

_____, E.W. Bierly, and G.C. Gill, 1961: Topographic influences on the behavior of stack effluents. *Proc. of the Am. Power Conf., XXIII*, 358-370.

Hinds, W.T., 1970: Diffusion over coastal mountains of southern California. *Atmos. Environ., 4*, 107-124.

Hīno, M., 1968: Computer experiment on smoke diffusion over complicated topography. *Atmos. Environ., 2*, 541-558.

Hosler, C.R., 1975: The meteorology program of the Environmental Protection Agency. *Bull. AMS, 56*, 1261-1270.

Hotchkiss, P.S. and F.H. Harlow, 1973: *Air Pollution Transport in Street Canyons*, EPA Interagency Agreement No. EPA-IAG-0122(D), U. of California, Los Alamos Scientific Lab., Los Alamos, N.M., 100 pp.

Hutcheon, R.J., R.H. Johnson, W.P. Loury, C.H. Black and D. Hadley, 1967: Observations of the urban heat island in a small city. *Bull. AMS, 48*, 7-9.

Jepson, A.F., and Weil, J.C., 1973: *Maryland Power Plant Air Monitoring Program Preliminary Results*, Paper #73-157 presented at the 66th Annual Meeting of the Air Poll. Control Assoc., Chicago, Illinois, June 1973, 19 pp.

Jutze, G. and E. Tabor, 1963: The continuous air monitoring program. *J. Air Poll. Control Assoc., 13*, 278-280.

Keagy, D.M., W.W. Stalker, C.E. Zimmer, and R.C. Dickerson, 1961: Sampling station and time requirements for urban air pollution survey. Part I: Lead Perioxide Candles and Dustfall Collectors. *J. Air Poll. Control Assoc., 11*, 270-280.

Larsen, R.I., W.W. Stalker, and C.R. Claydon, 1961: The radial distribution of sulfur dioxide source strength and concentration in Nashville. *J. Air Poll. Control Assoc., 11*, 529-534.

Leahey, D.M., 1974: A study of air flow over irregular terrain. *Atmos. Environ., 8*, 783-791.

Leavitt, J.M., F. Pooler, Jr., and R.C. Wanta, 1957: Design and interim Meteorological evaluation of a community network for meteorological and air quality measurements. *J. Air Poll. Control Assoc., 7*, 211-215.

Liberti, A. and G. Devitofrancesco, 1967: Evaluation of sulfur compounds in Atmospheric Dust. *Proc. Symp. Physico-chemical Trans. of Sulfur Compounds in the Atmos. and the Formation of Acid Smogs*, Organization for Economic Cooperation and Development, Mainz, Germany, June, 1967.

Ludwig, F.L. and J.H.S. Kealoha, 1975: *Selecting Sites for Carbon Monoxide Monitoring*, EPA Contract 68-02-1471, Environmental Protection Agency, Research Triangle Park, N.C., 149 pp.

Martin, D.O., P.A. Humphrey, and J.L. Dicke, 1967: *Interstate Air Pollution Study, Phase II Project Report, V. Meteorology and Topography*, in-house report, U.S. Dept. of Health, Education and Welfare, PHS, National Center for Air Pollution Control, Cincinnati, Ohio, 42 pp.

Mitchell, M.J., 1961: The temperature of cities. *Weatherwise, 14*, 224-229.

Montgomery, T.L., J.W. Frey, and W.B. Morris, 1975: Intermittant control systems. *Environ. Sci. and Tech., 9*, 528-533.

Morgenstern, P. and K.A. Hagg, 1972: A system for abatement control strategy evaluation. *J. Air Poll. Control Assoc., 22*, 774-778.

Munn, R.E. and I.M. Stewart, 1967: The use of meteorological towers in urban air pollution programs. *J. Air Poll. Control Assoc., 17*, 98-101.

NAPCA, 1970: *Air Quality Criteria for Sulfur Oxides*, in-house report, AP-50, National Air Pollution Control Administration, U.S. Dept. of Health, Education and Welfare, Washington, D.C., 178 pp.

NAS, 1975: *Air Quality and Stationary Source Emission Control*, prepared for the Committee on Public Works pursuant to S. Rev. 135; Serial No. 94-4, U.S. Gov't. Printing Off., Washington, D.C., 909 pp.

Oke, T.R., 1973: City size and the urban heat island. *Atmos. Environ., 7*, 769-779.

_____, 1975: Urban heat island dynamics in Montreal and Vancouver. *Atmos. Environ., 9*, 191-200.

Ott, W.R., 1975: *Development of Criteria for Siting Air Monitoring Stations*, Paper # 75-14.2, presented at the 68th Annual Meeting of the Air Pollution Control Assoc., Boston, Mass, June 1975.

Owers, M.J. and A.W. Powell, 1974: Deposition velocity of sulpher dioxide on land and water surfaces using a ^{35}S tracer method. *Atmos. Environ., 8*, 67-68.

Pasquill, F., 1961: The estimation of the dispersion of windborne material. *Meteorol. Mag. (London), 90*, 33-49.

Paulus, J.J. and A.T. Rassano, 1973: *Siting of Air Quality and Meteorological Monitoring Stations to Investigate Air Quality Effects of a Point Source.* 3rd Int'l Ocean Air Cong., Duesseldorf, W. Germany, 133-136.

Pelletier, J., 1963: Difficulties encountered in the measurement of air pollution and in the interpretation of results. *Int'l. J. Air & Water Poll.*, *7*, 973-978.

Peters, L.K., 1975: On the criteria for the occurrence of fumigation inland from a large lake. *Atmos. Environ.*, *9*, 809-816.

Petersen, J.P., 1969: *The Climate of Cities: A Survey of Recent Literature*, in-house report, Publ. No. AP-59, National Air Pollution Control Admin., U.S. Dept. of Health, Education and Welfare, Raleigh, N.C., 48 pp.

Pooler, Jr., F., 1963: Airflow over a city in terrain of moderate relief. *J Appl. Meteor.*, *2*, 446-456.

_____, 1974: Network requirements for the St. Louis regional air polltuion study. *J. Air Poll. Control Assoc.*, *24*, 228-231.

Roberts, J.J., E.J. Croke, A.S. Kennedy, J.E. Norco, and L.A. Conley, 1970: *Chicago Air Pollution System Analysis Program: A Multiple-Source Urban Atmospheric Dispersion Model*, in-house report, Publ. # ANL/ES-CC-007, Argonne National Laboratory, Argonne, Illinois, 148 pp.

Robinson, E. and R.C. Robbins, 1968: *Sources, Abundance and Fate of Gaseous Atmospheric Pollutants*, SRI Report No. PR-6755, Stanford Research Institute, Menlo Park, Calif., 127 pp.

_____ and _____, 1970: Gaseous sulfur pollutants from urban and natural sources. *J. Air Poll. Control Assoc.*, *20*, 233-235.

Rossano, A.T., 1956: The joint city, county, state, and federal study of air pollution in Louisville. *J. Air Poll. Control Assoc.*, *6*, 176-181.

Shepard, J.G., 1974: Measurements of the direct deposition of sulphur dioxide onto grass and water by the profile method. *Atmos. Environ.*, *8*, 69-74.

Sherlock, R.H. and E.A. Stalker, 1941: *A Study of Flow Phenomena in the Wake of Smoke Stacks*. Bull. #29, Dept. of Engineering Res., U. of Michigan, Ann Arbor, Michigan.

Simon, C., 1969: *New York City's Meteorological Program*, presented at the Mid-Atlantic States Section, APCA, Semi-Annual Tech. Conf., Philadelphia, Pa., March 21, 1969, 9 pp.

Slade, D.H.(editor), 1968: *Meteorology and Atomic Energy, 1968*, Publ. No. TID-24190, Air Resources Labs., Environ. Sci. Serv., Admin. (ESSA), U.S. Dept. of Commerce, Washington, D.C., 445 pp.

Smith, D.B., 1968: Tracer study in an urban valley. *J. Air Poll. Control Assoc.*, *18*, 600-604.

Spedding, D.J., 1972: Surphur dioxide absorption by sea water. *Atmos. Environ.*, *6*, 583-586.

Spicer, C.W., J.L. Gemma, D.W. Joseph, P.R. Stricksel, and G.F. Ward, 1976: *The Transport of Oxidant Beyond Urban Areas*, EPA Contract 68-02-1714, Off. of Res. and Dev., ESRL, U.S. Environmental Protection Agency, Research Triangle Park, N.C., 235 pp.

Start, G.E., C.R. Dickson, and L.L. Wendell, 1973: *Diffusion in a Canyon within Rough Mountainous Terrain*, in-house report, Publ. # NOAA-TM-ERL-ARL-38, Environ. Res. Labs., Air Resources Lab., NOAA, Idaho Falls, Id., 43 pp.

_____, N.R. Ricks, C.R. Dickson, 1974: *Effluent Dilutions Over Mountainous Terrain*, NOAA Tech. Memo., ERL ARL-51, Environ. Res. Labs., Air Resources Lab., NOAA, Idaho Falls, Id., 162 pp.

Stasiuk, N.W. and P.E. Coffey, 1975: Evidence of atmopsheric transport of ozone into urban areas. *Environ. Sci. and Tech.*, *9*, 59-62.

Stern, A.C., H.C. Wohlers, R.W. Boubel, and W.P. Lowry, 1973: *Fundamentals of Air Pollution*, Academic Press, New York, N.Y., 492 pp.

Stockton, E.L., 1970: Experience with a computer oriented air monitoring program. *J. Air Poll. Control Assoc.*, *20*, 456-460.

Turner, D.B., 1968: The diurnal and day-to-day variations of fuel usage for space heating in St. Louis, Missouri. *Atmos. Environ.*, *2*, 339-351.

_____, 1974: *Workbook of Atmospheric Dispersion Estimates*, in-house report, 7th printing, Publ. # AP-26, Office of Air Programs, U.S. Environmental Protection Agency, Research Triangle Park, N.C., 84 pp.

Urone, P., H. Lutsep, C.M. Noyes, and J.F. Parcher, 1968: Static studies of sulfur dioxide reactions in air. *Environ. Sci. Tech.*, *2*, 611-618.

U.S. Geological Survey, 1969: *Topographic Maps*, USGS, Washington, D.C., 22 pp.

_____, 1974: *Orthophotoquad Index*, USGS, Washington, D.C., (chart).

Van der Hoven, I., 1967: Atmospheric transport and diffusion at coastal sites. *Nuclear Safety*, *8*, 490-499.

Wohlers, H.C., N.M. Trieff, H. Newstein, and W. Stevens, 1967: Sulfur dioxide adsorption on - and desorption from teflon, tygon, glass, stainless steel, and aluminum tubings. *Atmos. Environ.*, *1*, 121-130.

Yamada, V.M., 1970: Current practices in the siting and physical design of continuous air monitoring stations. *J. Air Poll. Control Assoc.*, *20* , 209-213.

APPENDIX*

A

SOURCES OF CLIMATOLOGICAL AND METEOROLOGICAL INFORMATION

(adapted from Ludwig and Kealoha, 1975)

* All references found in this appendix are listed in Section 6.0 (References) of the main text.

A. SOURCES OF CLIMATOLOGICAL AND METEOROLOGICAL INFORMATION

One of the most helpful publications specifically designed to assist potential users of climatological data is called "Selective Guide to Climatic Data Sources," Key to Meteorological Records Documentation Number 4.11, prepared by the staff at the National Climatic Center, Ashville, N.C., for sale by the Government Printing Office, Washington, D.C. Its format indicates the publication(s) in which various climatological categories (temperature, precipitation, wind, humidity, and so on) may be found. Although this publication refers primarily to published climatological data, a wealth of unpublished climatological summaries are also available on special order from the files of the National Climatic Center. An index to the summaries that can be ordered is given in the "Guide to Standard Weather Summaries," NAVAIR 50-IC-534, U.S. Navy, March 1968.

The National Climatic Center makes every effort to obtain a copy of all meteorological records collected in the United States. These data are available and can be ordered on microfilm, magnetic tape, hard copies, or as copies of raw data. The address and phone number are:

- Director, National Climatic Center
  Federal Building
  Ashville, North Carolina 28801
  Telephone: (704) 258-2850

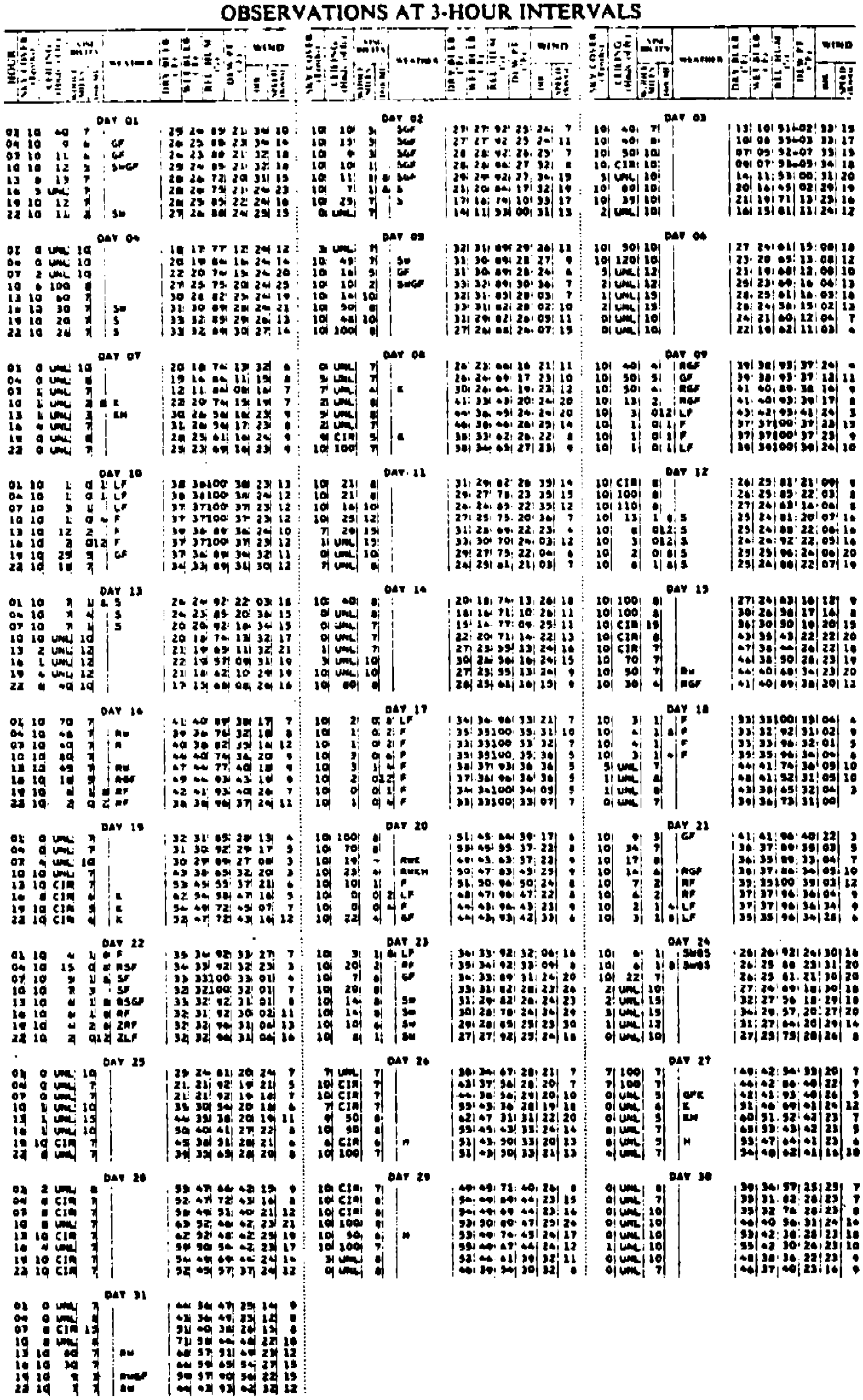
The Center answers inquiries and analyzes, evaluates, and interprets data. Routine letters or telephone inquiries are usually answered without charge; other services are provided at cost.

The bulk of the data at the Climatic Center are meteorological observations made at airfields by the National Weather Service, the Federal Aviation Administration, and the Defense Department. Table A-1 shows an example of the kind of information to be found on a three-hourly tabulation for one month at one station. Climatic information is seldom available to the extent that it will be desired, but ingenuity can often be used to ferret out sources not generally available from the usual public data repositories.

At the State and regional level, fire stations, highway and transportation departments, environmental studies groups, air pollution districts, and utility districts may have continuing meteorological records or special weather studies available. A call directly to these agencies may result in a data source not available anywhere else.

TABLE A-1. Example of Meteorological Records Available from the NCC.

OBSERVATIONS AT 3-HOUR INTERVALS



REFERENCE NOTES

CEILING COLUMN—
UNL indicates an unlimited ceiling.
CIR indicates a cirriform cloud ceiling of unknown height.

WEATHER COLUMN—
- * Tornado
- T Thunderstorm
- O Squall
- R Rain
- RW Rain showers
- ZR Freezing rain
- L Drizzle
- ZL Freezing drizzle
- S Snow
- SP Snow pellets
- IC Ice crystals
- SW Snow showers
- SG Snow grains
- E Sleet
- A Hail
- AP Small hail
- F Fog
- IF Ice fog
- GF Ground fog
- BD Blowing dust
- BN Blowing sand
- BS Blowing snow
- BY Blowing spray
- K Smoke
- H Haze
- D Dust

WIND COLUMNS—

Directions are those from which the wind blows, indicated in tens of degrees from true North: i. e., 09 for East, 18 for South, 27 for West. Entry of 00 in the direction column indicates calm.

Speed is expressed in knots; multiply by 1.15 to convert to miles per hour.

ADDITIONAL DATA

Other observational data contained in records on file can be furnished at cost via microfilm or microfiche copies of the original records. Inquiries as to availability and costs should be addressed to:

Director
National Weather Records Center
Federal Building
Asheville, N. C. 28801

Schools, colleges, industrial complexes (such as oil refineries), agricultural research stations, radio-TV stations, and electrical power plants may cooperate with a data collection program if asked.

The following publications provide important information concerning useful data sources.

1) Air Pollution Control Association (1973-1974): *Directory, Government Air Pollution Agencies*, published in cooperation with the Office of Air Programs, EPA. This directory lists federal, state, regional, and county agencies conducting air pollution programs. Names of officials, titles, addresses, and telephone numbers are given. Wirte to W.T. Beery, Editor, Directory Governmental Air Pollution Agencies, Air Pollution Control Association, 4400 5th Ave., Pittsburg, Pa. 15213.

2) World Weather Records, Smithsonian Misc. Collections, Vol. 79, Publication 2913, Assembled and arranged for publication by H.H. Clayton, published by the Smithsonian Institution, August 1927. This reference book contains monthly and annual means of pressure, temperature, and totals of rainfall.

A more extensive collection consisting of climatological data for selected airfields and for the climatic areas in which they are located has been compiled by the USAF Environmental Technical Application Center (ETAC), Building 159, Navy Yard Annex, Washington, D.C. 20333. This series is also being published by the U.S. Naval Weather Serice, Navy Yard, Washington, D.C. 20390, under the title, *U.S. Naval Weather Service World-Wide Airfield Summaries*. Table A-2 lists the available volumes in this series. Volume VIII contains summaries for the United States. Information requests should be addressed to:

- The National Technical Information Service (NTIS)
  Springfield, Virginia 22151.

3) *The Climatic Atlas of the United States*, 1968, is a comprehensive series of monthly and annual analyses showing the national distirbution of mean, normal, and/or extreme values of temperature, precipitation, wind, pressure, relative humidity, dewpoint, sunshine, sky cover, heating degree days, solar radiation and evaporation. It was prepared by the Environmental Data Service, NOAA, U.S. Department of Commerce, for sale by the Superintendent of Documents, Washington, D.C.

4) *Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States*, by George C. Holzworth, illustrates seasonal and annual, morning and afternoon mean mixing heights, wind speeds, and normalized pollutant concentrations that were exceeded 10, 25, and 50 percent of the time for specified city sizes. Copies of this report Office of Air Programs Pub. No. AP-101) may be ordered from the Office of Tech. Information & Publs., Off. of Air Programs, EPA, Research Triangle Park, N.C. 27711.

TABLE A-2

Published Volumes of World-Wide Airfield Summaries

Volume	Name	NTIS Accession No.
I	Southeast Asia (revised)	AD-706-355
II	Middle East	
	Part 1	AD-662-425
	Part 2	AD-622-427
III	Far East	AD-662-426
IV	Canada-Greenland-Iceland	AD-662-424
V	Australia-Antarctica (including S. Pacific Is.)	AD-662-648
VI	South America	
	Part 1	AD-664-828
	Part 2	AD-664-829
VII	Central America	AD-671-845
VIII	United States of America	
	Part 1. W. Coast, Western Mtns., & Great Basin	AD-688-472
	Part 2. Rocky Mtns. and Northwest Basin	AD-689-792
	Part 3. Central Plains	AD-693-491
	Part 4. Great Lakes	AD-696-971
	Part 5. Mississippi Valley	AD-699-917
	Part 6. Southeastern Region	AD-701-719
	Part 7. East Coast and Appalachian Region	AD-703-606
	Part 8. Alaska and Hawaii	AD-704-607
IX	Africa	
	Part 1. Northern Half	AD-682-915
	Part 2. Southern Half	AD-682-915
X	Europe	
	Part 1. Scandinavia and Northern Europe	
	Part 2. Low Countries and British Isles	
	Part 3. Alps and Southwest Europe	
	Part 4. Mediterranean	

The National Climatic Center will prepare special data summaries. They also have standard computer programs available for special summaries. One of the most useful summaries for air pollution studies is that prepared by the STAR program. It is a joint frequency distribution of atmospheric stability and wind speed and direction. The atmospheric stability is calculated objectively from the cloud cover and wind data. This stability algorithm is based on the work of Pasquill (1961). The summaries can be based on any extended period of record with separate outputs for the months or seasons, as well as an annual summary. There are some pollution models that use the output of STAR program as part of their input requirements. The National Climatic Center has computed these summaries for over 250 weather stations in the United States. These stations are listed in Table A-3.

TABLE A-3

List of Stations for Which Stability-Wind-Rose Tables have been Prepared*

Stations for which Local Climatological Data are issued, as of January 1, 1969

	ALABAMA
abc	Birmingham
abc	Huntsville
abc	Mobile
abc	Montgomery
	ALASKA
abc	Anchorage
abc	Annette
abc	Barrow
abc	Barter Island
abc	Bethel
ab	Bettles
ab	Big Delta
abc	Cold Bay
abc	Fairbanks
ac	Farewell
abc	Gulkana
abc	Homer
abc	Iliamna
abc	Juneau
abc	King Salmon
abc	Kotzebue
abc	McGrath
ab	Nenana
abc	Nome
abc	St. Paul Island
abc	Shemya
abc	Summit
abc	Talkeetna
ab	Tanana
abc	Unalakleet
abc	Yakutat
	ARIZONA
abc	Flagstaff
abc	Phoenix
abc	Tucson
abc	Winslow
abc	Yuma
	ARKANSAS
abc	Fort Smith
abc	Little Rock
	CALIFORNIA
abc	Bakersfield
ac	Bishop
ac	Blue Canyon
ac	Eureka
abc	Fresno
abc	Long Beach
	Los Angeles
abc	Airport
ac	Civic Center
ac	Mt. Shasta
abc	Oakland
abc	Red Bluff
abc	Sacramento
ac	Sandberg
abc	San Diego
	San Francisco
abc	Airport
ac	City
ac	Santa Maria
abc	Stockton
	COLORADO
ac	Alamosa
abc	Colorado Springs
abc	Denver
abc	Grand Junction
abc	Pueblo
	CONNECTICUT
abc	Bridgeport
abc	Hartford
ac	New Haven
	DELAWARE
abc	Wilmington
	DISTRICT OF COLUMBIA
abc	Washington
	FLORIDA
ac	Apalachicola
abc	Daytona Beach
abc	Fort Myers
abc	Jacksonville
abc	Key West
ac	Lakeland
abc	Miami
abc	Orlando
abc	Pensacola
abc	Tallahassee
abc	Tampa
abc	West Palm Beach
	GEORGIA
abc	Athens
abc	Atlanta
abc	Augusta
abc	Columbus
abc	Macon
ac	Rome
abc	Savannah
	HAWAII
abc	Hilo
abc	Honolulu
abc	Kahului
abc	Lihue
	IDAHO
abc	Boise
ac	Lewiston
abc	Pocatello
	ILLINOIS
ac	Cairo
	Chicago
abc	Midway Airport
ab	O'Hare Airport
abc	Moline
abc	Peoria
abc	Rockford
abc	Springfield
	INDIANA
abc	Evansville
abc	Fort Wayne
abc	Indianapolis
abc	South Bend
	IOWA
abc	Burlington
abc	Des Moines
ac	Dubuque
abc	Sioux City
abc	Waterloo
	KANSAS
abc	Concordia
abc	Dodge City
abc	Goodland
abc	Topeka
abc	Wichita
	KENTUCKY
abc	Lexington
abc	Louisville
	LOUISIANA
abc	Alexandria
abc	Baton Rouge
abc	Lake Charles
abc	New Orleans
abc	Shreveport
	MAINE
ac	Caribou
abc	Portland
	MARYLAND
abc	Baltimore
	MASSACHUSETTS
	Boston
abc	Airport
ac	Blue Hill Obs.
abc	Nantucket
abc	Worcester
	MICHIGAN
abc	Alpena
	Detroit
abc	City Airport
abc	Detroit Metro AP
abc	Flint
abc	Grand Rapids
abc	Houghton Lake
abc	Lansing
ac	Marquette
abc	Muskegon
abc	Sault Ste. Marie

C O N T I N U E D

* Only those stations having at least the "b" indicated.

Table A-3. Continued.

	MINNESOTA
abc	Duluth
abc	International Falls
abc	Min'p'l's-St. Paul
abc	Rochester
ac	St. Cloud
	MISSISSIPPI
abc	Jackson
abc	Meridian
	MISSOURI
abc	Columbia
abc	Kansas City
abc	St. Joseph
abc	St. Louis
abc	Springfield
	MONTANA
abc	Billings
abc	Glasgow
abc	Great Falls
abc	Havre
abc	Helena
abc	Kalispell
c	Miles City
abc	Missoula
	NEBRASKA
abc	Grand Island
ac	Lincoln
ac	Norfolk
abc	North Platte
abc	Omaha
abc	Scottsbluff
ac	Valentine
	NEVADA
abc	Elko
abc	Ely
abc	Las Vegas
abc	Reno
abc	Winnemucca
	NEW HAMPSHIRE
abc	Concord
ac	Mt. Washington
	NEW JERSEY
	Atlantic City
abc	Airport
a	State Marina
abc	Newark
ac	Trenton
	NEW MEXICO
abc	Albuquerque
ac	Clayton
abc	Roswell
	NEW YORK
abc	Albany
	Binghamton
abc	Airport
abc	Buffalo
	New York
abc	Central Park
abc	Int'l. Airport
abc	LaGuardia Field
abc	Rochester
abc	Syracuse
	NORTH CAROLINA
abc	Asheville
abc	Cape Hatteras
abc	Charlotte
abc	Greensboro
abc	Raleigh
abc	Wilmington
	NORTH DAKOTA
abc	Bismarck
abc	Fargo
abc	Williston
	OHIO
abc	Akron-Canton
	Cincinnati
ac	Abbe Obs.
abc	Airport
abc	Cleveland
abc	Columbus
abc	Dayton
abc	Mansfield
abc	Toledo
abc	Youngstown
	OKLAHOMA
abc	Oklahoma City
abc	Tulsa
	OREGON
abc	Astoria
abc	Burns
abc	Eugene
ac	Meacham
abc	Medford
abc	Pendleton
abc	Portland
abc	Salem
ac	Sexton Summit
	PACIFIC ISLANDS
ac	Guam
abc	Johnston
abc	Koror
abc	Kwajalein
abc	Majuro
abc	Pago Pago
abc	Ponape
abc	Truk (Moen)
abc	Wake
abc	Yap
	PENNSYLVANIA
abc	Allentown
abc	Erie
abc	Harrisburg
abc	Philadelphia
	Pittsburgh
abc	Airport
ac	City
ac	Reading
abc	Scranton
abc	Williamsport
	RHODE ISLAND
ac	Block Island
abc	Providence
	SOUTH CAROLINA
	Charleston
abc	Airport
a	City
abc	Columbia
abc	Greenville-Spartanburg
	SOUTH DAKOTA
abc	Aberdeen
abc	Huron
abc	Rapid City
abc	Sioux Falls
	TENNESSEE
abc	Bristol
abc	Chattanooga
abc	Knoxville
abc	Memphis
abc	Nashville
	Oak Ridge
a	Area Stations
ac	City
	TEXAS
abc	Abilene
abc	Amarillo
abc	Austin
abc	Brownsville
abc	Corpus Christi
abc	Dallas
abc	Del Rio
abc	El Paso
abc	Fort Worth
ac	Galveston
abc	Houston
abc	Lubbock
abc	Midland
abc	Port Arthur
abc	San Angelo
abc	San Antonio
abc	Victoria
abc	Waco
abc	Wichita Falls
	UTAH
ac	Milford
abc	Salt Lake City
ac	Wendover
	VERMONT
abc	Burlington
	VIRGINIA
ac	Lynchburg
abc	Norfolk
abc	Richmond
abc	Roanoke
a	Wallops Island
	WASHINGTON
abc	Olumpia
abc	Quillayute Airport
abc	Seattle-Tacoma AP
abc	Spokane
ac	Stampede Pass
ac	Walla Walla
abc	Yakima
	WEST INDIES
abc	San Juan, P. R.
ac	Swan Island
	WEST VIRGINIA
abc	Beckley
abc	Charleston
ac	Elkins
abc	Huntington
ac	Parkersburg
	WISCONSIN
abc	Green Bay
abc	La Crosse
abc	Madison
abc	Milwaukee
	WYOMING
abc	Casper
abc	Cheyenne
abc	Lander
abc	Sheridan

a. Monthly summary issued.

b. Monthly summary includes 3-hourly observations.

c. Annual Summary issued.

A P P E N D I X *

B

Suggested Approaches for Determining Worst Case SO_2 Patterns and Associated Meteorology

PART I. Multi-Source Urban Settings
PART II. Isolated Point Source Monitoring

* All references found in this appendix are listed in Section 6.0 (References) of the main text.

B. SUGGESTED APPROACHES FOR DETERMINING WORST CASE SO_2 PATTERNS AND ASSOCIATED METEOROLOGY

This Appendix was prepared to serve as guidance for utilizing short-term diffusion model simulations in selecting monitoring sites. Such simulations may be required to determine approximate locations of monitoring sites for measuring short-term peak concentrations under near worst case conditions. Part I addresses the situation in multi-source urban settings. Part II addresses isolated point source monitoring.

It is strongly recommended that a diffusion meteorologist be consulted in developing procedures for specific applications. Presented below are approaches that address the problem areas; they should not be construed as constituting the only approaches.

B.I MULTI-SOURCE URBAN SETTINGS

This suggested approach utilizes the programming logic incorporated in the AQDM computer program. What is presented here is not a detailed listing of a program modification but a description of a suggested modification and how such a modification, when used in conjunction with wind direction persistence tables, can estimate the approximate locations where the short-term concentration peaks should occur. The program modifications themselves could be accomplished quite easily with the aid of a diffusion meteorologist.

The AQDM utilizes emission rates from a set of pollutant sources and a joint frequency distribution of wind speed, wind direction, and atmospheric stability (stability-wind-rose, SWR). The total concentration at a specific receptor is obtained by utilizing each element of the SWR to calculate the partial concentration that a source contributes to the receptor and summing over all sources. There are six wind speed classes each representing a wind speed range, five stability classes, and sixteen wind directions for a total of 480 elements or "cells" that comprise the SWR. However, normally only about one-half of the cells are "filled" and only those that establish the source as being upwind of a receptor are utilized.

Utilizing the winter quarter SWR (Dec-Jan-Feb) and making appropriate changes in "print" or "write" statements, it would be possible to print 480 (or a number equal to the number of filled cells) maps of pollutant concentrations, one map for each combination of wind speed range, wind direction, and stability class. All 480 maps could be stored on tape and only those five or so maps having the highest concentration peaks at any receptor need be printed out and analyzed. It is recommended that the SWR be "normalized" by changing the indicated frequency of occurrence of each meteorological combination (cell) to a constant value for all cells. This value could be "1" or the inverse of the number of cells filled, etc. The purpose of this procedure is to eliminate the bias due to relative frequencies of occurrence. For example, a high frequency of occurrence of a given combination could actually be composed of many short periods, no individual period being characterized by a high concentration; on the other hand, a low frequency of occurrence may consist of a single long period of persistent wind direction resulting in a high concentration peak. Therefore, the use of normalized meteorology along with wind direction persistence information will more likely reveal the location of the peak concentrations. Another important point is that the distribution of sources, source strengths and emission heights in combination with a unique meteorological condition results in the highest ground-level concentrations (the near worst case meteorological condition).

The persistence of the wind direction over the worst case condition determines the averaging time of the peak. Three basic time periods are recommended to be considered. For the three-hour peak analyses, the daytime period from 1000 to 1900 LST and the nighttime period (2000-0900LST) should be considered separately. For the 24-hour peak analysis, consider the 24-hour period 0000 to 2400 LST.

Wind direction persistence tables for the weather station of interest for each of the three basic time periods may be requested from the National Climatic Center or generated by a computer program using LCD data (wind). A suggested format is shown in Table B-1, or graphically, in Figure B-1. Since observations are taken at 3-hour intervals, two consecutive observations having the same wind direction would constitute a 3-hour persistence case; three consecutive observations, a 6-hour case; etc.

TABLE B-1

Tabulated Persistence Data for NW Wind Situation
(192 obs/yr, 7% of total wind obs)

NW Wind	Persistence (hours)							
	3	6	9	12	15	18	21	24
Frequency (#)	40	12	7	5	4	3	2	1
Frequency (%) (192 base)	21	6	4	3	3	2	1	1
Median[1] Speed / Modal[2] Speed (%)	$\frac{15}{17}$ (50)	$\frac{11}{9}$ (30)	$\frac{9}{11}$ (60)	$\frac{12}{10}$ (25)				

1 Wind speed that divides sample in half.

2 Most frequently occurring wind speed.

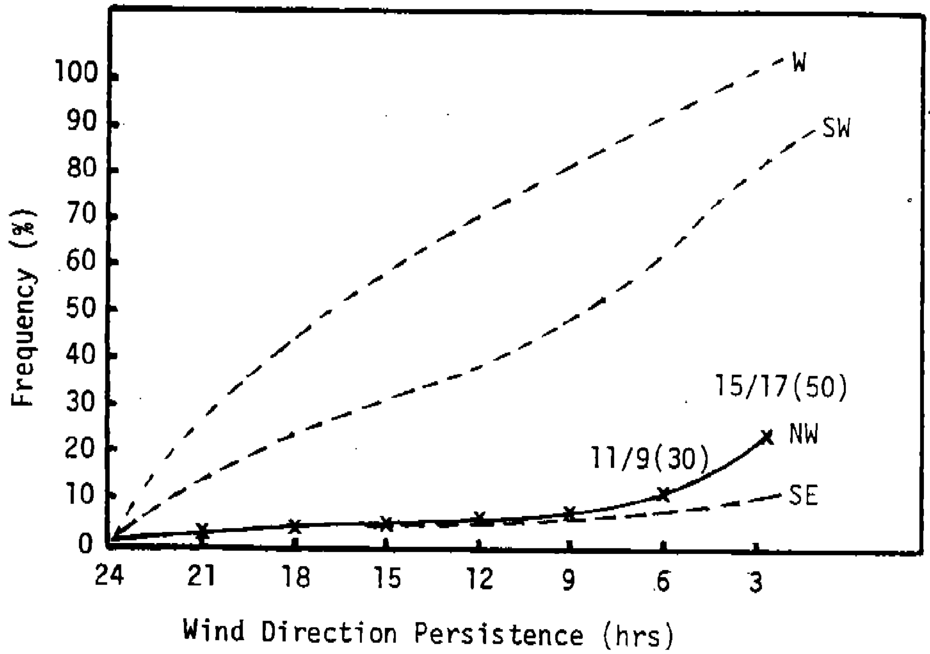


FIGURE B-1. Graphical presentation of persistence data, NW wind case from Table B-1. Graphs may be prepared by season, day/night, etc.

B.II ISOLATED POINT SOURCE MONITORING

This approach also utilizes standard Gaussian diffusion concepts. It is assumed that the reader is familiar with the various kinds of graphical solutions to the Gaussian point source diffusion equation such as that shown in Figure B-2. In any case, "Turner's Workbook" (Turner, 1974) contains most of the support information and should be consulted (also, see Appendix E, Sec.E.3).

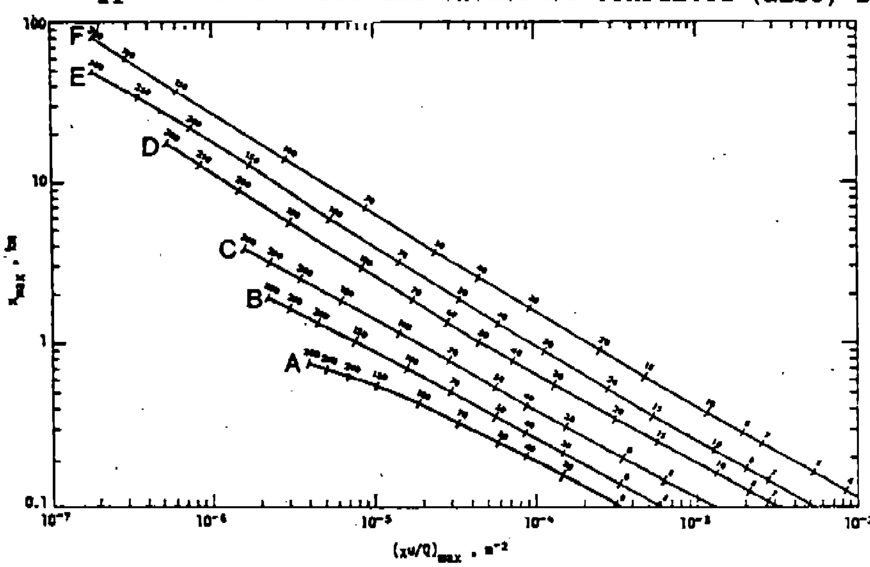


FIGURE B-2.

Distance of maximum concentration & maximum $\chi u/Q$ as a function of stability (curves) and effective height (m) of emission (numbers).

The approach presented here is generally applicable to terrain settings ranging from flat to moderately rough and irregular. Its application to rough and irregular terrain can be accomplished by substituting appropriate diffusion coefficients, such as those presented by Bowne (1973) for those valid only for flat terrain in the Gaussian point source equation. In this manner, graphical solutions can be prepared for various terrain settings. Suggested approaches for dealing with the 3-hour and 24-hour averaging times are given below.

B.II.1 Three-Hour Peak Concentrations, Their Locations, and Associated Meteorology

The critical wind speeds for each stability class (A, B, and C) are first determined; these winds produce the highest ground-level concentrations downwind of the plant. The wind directions associated with the critical wind speeds (see Table B-2 for example) establish the downwind azimuths along which candidate siting areas are established. Graphical solutions to the Gaussian equation in a form similar to Figure B-2 is used to determine their approximate distances downwind. Next, a decision has to be made regarding selecting the final site or sites. Since stability Class A will usually be associated with the highest peak but may not have the highest frequency of occurrence, two sites may be appropriate:

a) one site associated with the most unstable stability class to measure the highest peak;

b) the other site associated with a high peak that occurs very often (see Table B-2, second column).

The meteorology associated with each of the above situations is the worst case meteorological condition for those situations.

B.II.2 Twentyfour-Hour Peak Concentrations, Their Locations, and Associated Meteorology

The situation associated with the 24-hour average impact is somewhat different than that associated with the 3-hour impact. The plant will probably not be operating at its peak production rate for 24 hours and the atmospheric stabilities may involve the full range of classes.

The following procedure is recommended:

- Determine the critical wind speed for stability class D (represents 24-hour average stability); in the calculalation of effective stack height, stack parameters should reflect the average daily emission rate. From wind persistence tables (e.g., Figure B-1) representative of the area of interest, ascertain the most persistent wind directions (e.g., the five or so of longest duration. The median and modal speeds associated with the directions are then noted. These speeds can

TABLE B-2*

Illustration of Use of Stability-Wind-Rose for Determining Site Locations Monitoring Isolated Point Sources

[Assume a critical wind speed of 2 knots; NNE direction from source: azimuth for monitoring the highest peak concentration; NE direction from source: azimuth associated with frequently occurring high peaks. Use Fig. B-2 for determining downwind distances. Verify via mobile sampling.]

Direction	Frequency Distribution Speed (knots)							
	1-3	4-6	7-10	11-16	17-21	>21	Average Speed	Total
N	19	35	15	0	0	0	5.0	69
NNE	15	29	8	0	0	0	5.0	52
NE	6	11	3	0	0	0	4.8	21
ENE	2	9	4	0	0	0	5.6	15
E	7	10	4	0	0	0	4.8	21
ESE	2	6	3	0	0	0	5.2	11
SE	9	4	1	0	0	0	3.6	14
SSE	2	3	0	0	0	0	4.0	5
S	16	14	4	0	0	0	4.2	34
SSW →	$\boxed{29}$	34	22	0	0	0	4.9	85
SW →	22	$\boxed{41}$	13	0	0	0	4.8	76
WSW	15	13	7	0	0	0	4.6	35
W	12	22	5	0	0	0	4.7	39
WNW	15	18	13	0	0	0	5.1	46
NW	4	18	15	0	0	0	5.9	37
NNW	7	12	6	0	0	0	4.8	25
Average	2.6	5.2	7.3	0	0	0	3.5	
Total	182	250	123	0	0	0		

Number of Occurrences of A Stability = 805
Number of Calms with A Stability = 221

* Station = 14703 Chicopee Falls, Mass 60-64 240B (adapted from NCC printout).

be used to characterize each persistence period; the modal speed should be used if it occurs about one-third of the time or more--otherwise the median speed may be more representative. Next, a judgemental decision must be made regarding the selection of the probable direction associated with the highest concentration. For this purpose, it can be assumed that the maximum concentrations are associated with the longest persistence periods with characteristic speeds nearest the critical wind speed. Therefore, if there are several persistence periods exceeding 24 hours in duration, the direction whose characteristics speed is closest to the critical wind speed may be deemed the worst case condition. Otherwise, the most persistent direction, regardless of its characteristic wind speed, will best represent such conditions, Graphical solutions to the Gaussian equation similar to Figure B-2 may be used to determine the required distance downwind to the siting area.

APPENDIX *

C

MOBILE SAMPLING

* All references found in this appendix are listed in Section 6.0 (References) of the main text.

TECHNICAL REPORT DATA

(Please read Instructions on reverse before completing)

1. REPORT NO. EPA-450/3-77-013	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Optimum Site Exposure Criteria For SO2 Monitoring		5. REPORT DATE April 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.J. Ball and G.E. Anderson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Center of Environment and Man, Inc. 275 Windsor Street Hartford, Connecticut 06120		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-2045
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Technical Support Division Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		
16. ABSTRACT Abstract enclosed within document.		

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(Report)* Unclassified	21. NO. OF PAGES 123
	20. SECURITY CLASS *(Page)* Unclassified	22. PRICE